AFIT/GEE/ENV/92S-2



# A MODEL FOR DETERMINING MODULAR HEAT RECOVERY INCINERATOR FEASIBILITY ON AIR FORCE INSTALLATIONS

THESIS

Arthur H. Anderson, Jr., Captain, USAF
and
Paul R. Munnell, Captain, USAF

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THESIS

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Arthur H. Anderson, Jr., B.S.

Captain, USAF

Paul R. Munnell, B.S.

Captain, USAF


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# Preface

The purpose of this study was to develop a comprehensive model for determining the feasibility of building modular heat recovery incinerators (HRIs) on Air Force installations. Although there are currently several models for determining the economic viability of a HRI, this model incorporates both environmental compliance and sociopolitical criteria, in addition to economics.

Several individuals deserve thanks for their help in accomplishing this thesis. First, we would like to thank our advisor, Major Michael Duncan. His idea for the topic and support of our research were greatly appreciated. Captain David Herman and Captain Heidi Brothers, our thesis committee members, also deserve thanks for their support.

Next, we would like to thank Mr. Kevin McLaughlin from the 2750th CES/DEMSS. The technical information he provided was instrumental in developing a test scenario for our model. We also wish to extend our thanks to Mr. Walt Stevenson of the USEPA Office of Air Quality and Standards, and Mr. Ralph Bernstein of the Montgomery County Solid Waste Management Department. Each provided us with access to a great deal of valuable information.

Finally, we would like to thank our wives, Anastasia and Sue. It was their love and understanding that gave us the strength to finish this major undertaking.

Arthur H. Anderson, Jr. Paul R. Munnell

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## Abstract

This study involves the construction of a model for determining the feasibility of building municipal solid waste (MSW) fired modular heat recovery incinerators (HRIs) on Air Force installations. The generation of the model includes the development of three gates.

Gate one presents current federal regulatory air emission requirements for various HRI pollutants. It identifies the two current HRI air pollution control configurations that provide sufficient emissions control in order to meet regulatory requirements. These devices are a spray dryer absorber (SDA) with a fabric filter (FF), or a SDA with an electrostatic precipitator (ESP).

Gate two presents a life-cycle cost (LCC) economic analysis methodology for evaluating HRI alternatives. Operational and cost data from 57 modular HRIs located in the United States facilitates the development of regression equations describing the capital and annual operating costs of a modular HRI with either a SDA/FF or a SDA/ESP. Actual cost and operating information from a central heating plant at Wright-Patterson AFB, Ohio, along with cost data from the regression equations, provides the basis for a trial LCC analysis involving the modular HRIs. Results of this hypothetical evaluation show that the LCCs for the modular HRIs

with either a SDA/FF or a SDA/ESP are both less than the LCC of replacing the existing boiler with a natural gas-fired boiler.

Gate three involves the generation of a Likert-scale survey used to evaluate the sociopolitical acceptability of the proposed HRI. Based on the survey results, this gate should indicate the level of effort and resources necessary to process the proposed HRI in accordance with National Environmental Policy Act (NEPA) requirements. Validation of this gate is recommended for future research.

The three gates in this model should be used together to evaluate the environmental, economic, and sociopolitical feasibility of modular HRIs on Air Force installations.

A MODEL FOR DETERMINING MODULAR
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# I. Introduction

## General Issue

National Situation. The United States has a large problem with municipal solid waste disposal. Municipal solid waste (MSW) is

> ...a mixture or a single stream of household, commercial, [and] institutional discards...not [including] industrial process or manufacturing discards, segregated medical waste, or construction debris. (66:5490)

MSW typically includes paper, yard wastes, glass, metals, plastics, food, and other discarded matter (see Figure 1).

Placing MSW in landfills is the most common method of disposal. "Most cities still send from two-thirds to three-fourths of their garbage to landfills" (4:35). Existing landfills are filling up at a rapid pace. According to the United States Environmental Protection Agency (USEPA), "one-third of the nation's existing landfill facilities [were] expected to close by 1991" (64:2-2). The USEPA also "expects nearly half of the 6,000 landfills now in use to be filled or closed down [by 1996]" (19:259) and projects that "...80 percent of the existing landfills will close [by 2011]" (64:2-2). Figure 2 shows the decline in available

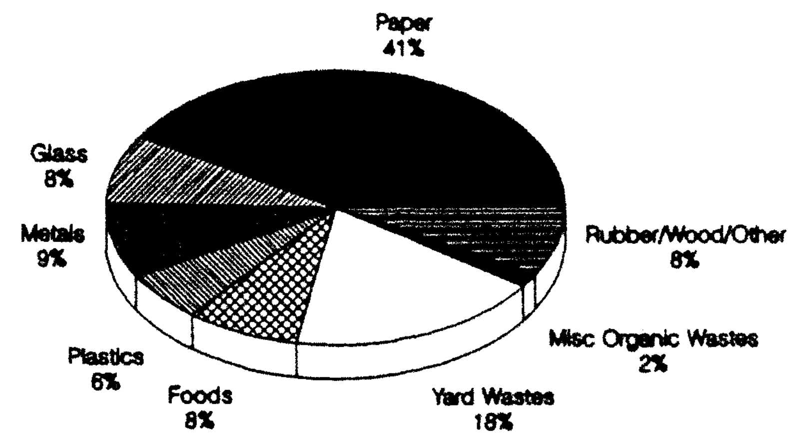


**Figure 1.** Contents of MSW Stream (73:3)

landfills versus the increase in solid waste generation from 1978 to 1988.

To deal with the problems associated with MSW disposal, the USEPA established a hierarchy of waste management options. The following list identifies this hierarchy, from most to least preferred:

1. <u>source reduction</u>: reducing the amount of wastes at the source through changes in the processes that generate them;

2. <u>recycling</u>: reusing and recycling wastes as substitutes for feedstocks/ingredients for industrial purposes;

3. <u>treatment</u>: destroying, detoxifying, or neutralizing wastes (including separation, volume reduction, or energy recovery);

4. <u>disposal</u>: discharging wastes into ambient water or air or injecting or depositing wastes into or onto the land. (60:54)

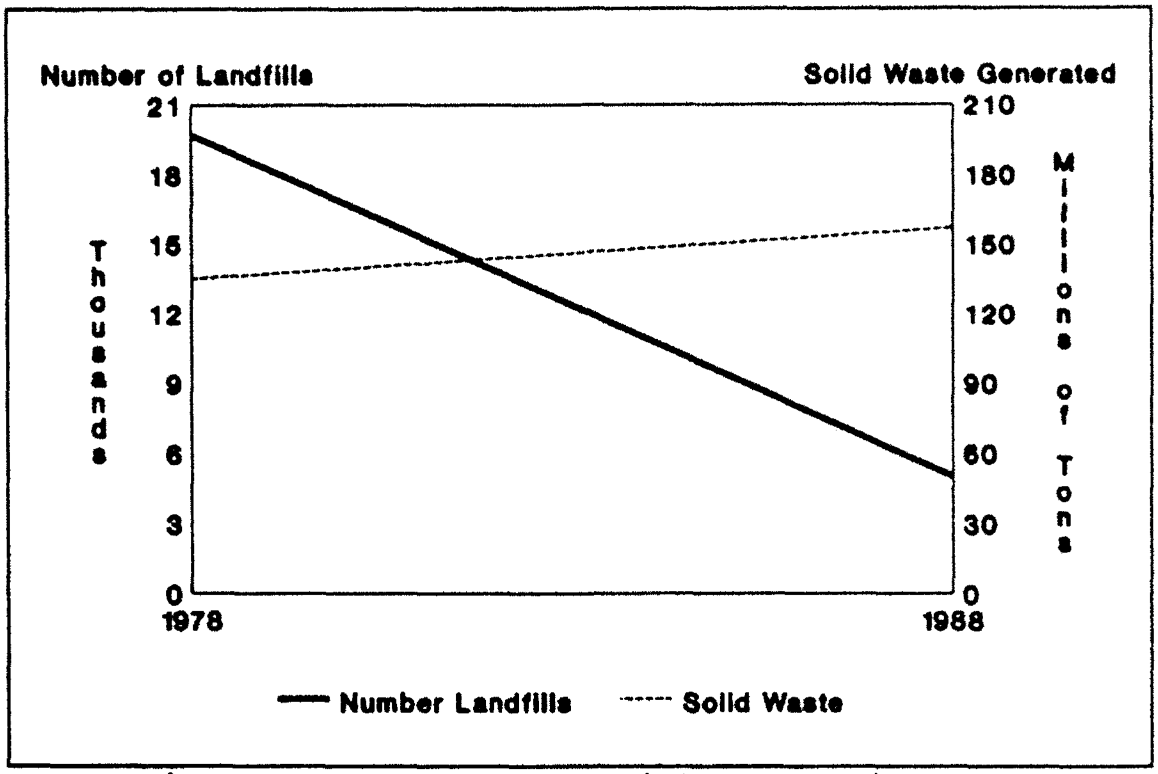


**Figure 2.** Number of Landfills vs. Solid Waste Generated (12:173)

Although source reduction and recycling are excellent means of decreasing MSW, treatment through heat recovery incineration reduces the volume of waste and provides useful energy. This practice is rapidly increasing throughout the nation. According to Teresa Austin's article, "Waste to Energy? The Burning Question," waste-to-energy facilities are on the rise (4:35). Waste-to-energy (WTE) facilities use refuse as fuel in a combustion process to generate electricity or heat. Heat recovery incinerators (HRIs) are WTE facilities that produce only heat. Over half of the 85 WTE plants currently operating in 28 states throughout the country are HRIs (4:35; 30:104-135). WTE facilities treat approximately 29 million tons (16 percent) of the country's MSW (4:35). The USEPA predicts there will be 350 WTE facilities by the year 2000 (59:5-2).

<u>Air Force Situation</u>. In addition to the national dilemma, the Air Force has its own unique environmental problems. Current Air Force operations generate a large amount of solid wastes. Costs to dispose of these wastes have increased dramatically. In response to numerous environmental issues (hazardous waste, municipal solid waste, recycling, and source reduction) the Air Force developed its Pollution Prevention Program (PPP). PPP policy and implementation guidance identifies Air Force philosophy.

> The Air Force will reduce...the generation of wastes whenever possible through source reduction and environmentally sound recycling. When...generating wastes cannot be avoided, we will minimize the undesirable impacts to our people and to the air, land, surface water, and ground water. (17:1)

General Merrill A. McPeak, Air Force Chief of Staff, recently submitted a list of environmental goals as part of the Air Force PPP. The following goals specifically address reduction of MSW disposal at Air Force installations:

> By the end of 1993, reduce municipal solid waste disposal by 10% from [a] 1992 baseline. By the end of 1995, reduce municipal solid waste disposal by 30% from [the] 1992 baseline. By the end of 1997, reduce municipal solid waste disposal by 50% from [the] 1992 baseline. (45:3-4)

Using WTE facilities, in conjunction with source reduction and recycling, may provide the Air Force a comprehensive MSW management program for achieving these reduction goals. WTE facilities offer an effective alternative for disposing of wastes. They reduce the volume of waste and provide a means of tapping the energy in MSW.

Many Air Force bases have large, manned central plants to produce facility heat and hot water. However, less than five percent of the 101 major Air Force installations in the continental United States and its possessions produce their own electricity (21). Therefore, replacing all or part of an existing central heat plant's capacity with a HRI should be the predominant focus at Air Force installations.

The decision to construct a HRI involves many environmental, economic, and sociopolitical factors. The Air Force needs a method of assessing these factors to determine HRI feasibility at individual installations.

## Specific Problem

Currently, there is no instrument to determine the viability of constructing HRIs on Air Force installations. The conventional practice is to base the evaluation strictly on an economic analysis without sufficient consideration of environmental and sociopolitical issues. The purpose of this research is to develop a model that considers all three issues (environmental, economic, and sociopolitical) in assisting Air Force installations in determining whether to construct HRIs.

## Investigative Questions

To solve the specific problem stated above, it is necessary to address the following investigative questions:

1. What environmental laws and regulations govern HRIs and how do they impact the decision to construct and operate them?

2. What specific information and analysis tool is required to perform an economic analysis of HRIs?

3. What sociopolitical issues impact construction of HRIs and how can their effects be measured?

## Scope of Study and Assumptions

This model only addresses modular HRIs. Modular incinerators are relatively small, low-cost, standardized, prefabricated facilities. Input sizes range from 15 to 200 tons per day (TPD) with steam outputs varying between 5,000 to 120,000 pounds per hour (24:94-99).

Refuse-converted HRIs are existing coal or oil-fired plants converted to use strictly refuse, or a mixture of refuse and fossil fuel, through modification of the fuel feeding system. This study excludes these incinerators for three reasons.

First, converting a coal or oil-fired plant tends to decrease the operational life of the boiler. Conventional boilers are designed to burn fossil fuels, which do not contain chlorine. The combustion of MSW releases chlorine, which can combine with hydrogen to form hydrochloric acid. Since conventional boilers are not designed for this operating environment, they will corrode quicker than HRI boilers designed specifically for MSW incineration.

Second, conversion may involve marrying equipment from two different manufacturers. This can create physical and operational compatibility problems. Finally, most manufacturers prefer to install their own incinerator packages to avoid compatibility problems. The majority of manufacturers do not advocate the conversion of existing fossil fuel plants to burn refuse. Rather, they recommend the installation of totally new systems. Consequently, neither manufacturers nor the EPA have the quantity of data on refuse conversion necessary for analysis in this study.

Regional HRIs are large facilities that normally import more than 200 TPD of MSW from several communities to meet demand. This study also excludes these facilities for the following reasons.

First, a regional facility would have to import large quantities of refuse. Even large Air Force installations generate less than 200 TPD of MSW. For example, in 1991, Wright-Patterson AFB generated approximately 115 TPD of MSW. This estimate is based on a generation rate of 230 cubic yards of refuse per day using a conversion factor of 1000 pounds of refuse per cubic yard (38). Importing refuse would reduce control of the waste stream entering the base, undermining recycling efforts and compounding problems associated with the heterogeneity of the waste fuel.

The second reason is the unpredictability of an adequate refuse supply. Factors such as the amount of solid waste generated in the service area, population, existing and proposed waste reduction/recycling programs, tipping fees at existing disposal facilities, and the remaining life of landfills in the area determine the supply of refuse for a regional facility (33:32). These parameters are far easier to measure and control within an Air Force installation than throughout a regional area surrounding the base.

A third point is the capability of base and community roads to support increased refuse-hauling traffic. Finally, the practice of accepting MSW from off-base sources may conflict with normal operations on an Air Force installation. The Air Force is not in the business of collecting garbage for final disposal.

This study assumes that recycling and source reduction programs are in place at the installation. However, it presumes that the MSW entering the proposed HRI facility is class one refuse-derived fuel (RDF), MSW that has not been processed except to remove oversized bulky waste (18:3.140). Appendix A describes the different classes of RDF. Since class one RDF has the lowest heat content (approximately 4500 BTU per pound of refuse), it provides a conservative estimate of the anticipated quality of the fuel (18:3.141).

## Overview of Research

This chapter introduces the current problems with MSW disposal as it pertains to both the nation and the Air Force. In addition to recycling and source reduction, it identifies heat recovery incineration as a possible alternative to manage MSW. In particular, chapter one proposes the development of a model considering environmental, economic, and sociopolitical issues to assist Air Force installations in determining whether to construct modular HRIs.

Chapter two is a review of current literature dealing with HRIs, including modular HRI technologies, environmental laws and regulations governing HRI operations, current pollution control methods for controlling emissions from HRIs, the methods of simple payback and life-cycle costing as means of performing economic analyses on HRIs, and socio-political factors including mitigative measures as well as public involvement techniques associated with constructing a HRI.

Chapter three explains the methodology used to construct the HRI decision model. It outlines the specific information requirements for each part of the model, identifies data collection requirements for each part, and proposes methods for analyzing the data.

Chapter four is the actual construction of the HRI decision model. Chapter five identifies the conclusions and recommendations for follow-on research.

# II. Literature Review

## Overview

This chapter focuses on current literature pertaining to HRI technology and to the environmental, economic, and sociopolitical issues relating to HRIs.

This chapter contains seven sections. Section one provides an overview of chapter two. Section two discusses modular HRI technology. Section three identifies the environmental laws and regulations governing HRI operation. Section four describes current HRI emission control technologies. Section five reviews the methods of simple payback and LCC techniques as means of performing economic analyses on HRIs. Section six identifies sociopolitical factors, mitigative measures, and public involvement techniques associated with constructing a HRI. Section seven provides a summary of chapter two.

## Modular HRI Technologies

Two widely used modular incinerator technologies are starved-air and excess-air. Most facilities incorporate the starved-air design (46:E-25). Starved-air systems have two combustion chambers. The primary chamber burns waste with 30 to 40 percent of stoichiometric requirements (48:C-2). The temperature in the primary chamber is maintained at about 1200°F, which reduces $NO_x$ emissions. Compared to the excess-air design, this process results in less turbulent combustion, which minimizes particulate emissions. The secondary chamber completes the combustion of gases from the primary chamber using "...100 to 150 percent of theoretical [stoichiometric] air requirements..." (48:C-2) at a temperature of about 1800°F (55:9). This oxidizes the carbon monoxide, burns remaining hydrocarbons, and helps to destroy dioxins and furans (55:9).

> An auxiliary burner in the secondary combustion chamber maintains these high temperatures for complete combustion. In most starved-air units, the secondary combustion temperatures are self-sustaining and the auxiliary burner operates intermittently. (55:9)

Excess-air designs also have two combustion chambers. The first chamber uses more than the stoichiometric requirement of air to achieve complete combustion of the waste. Excess-air produces a higher temperature in the first chamber, enhancing carbon monoxide oxidation as well as hydrocarbon and dioxin/furan destruction. Unfortunately, this can also increase $NO_x$ levels and create more combustion gas turbulence, which increases suspension of fly ash (particulates) in the exhaust gases. Increasing the size of the first chamber is one method of reducing turbulence (55:9). The secondary chamber of the excess-air unit operates similar to the secondary chamber of the starved-air unit, combusting gases from the primary chamber using 100 to 150 percent stoichiometric air requirements (48:C-2). Auxiliary burners maintain temperatures of 1600°F to 1800°F for complete combustion (55:9).

Modular HRIs can either operate independently or tie into existing infrastructure. They have "...particular value as an additive to an existing steam system, such as a central heating plant for an institution" (46:E-26). Examples of modular HRIs currently in operation and their uses in a variety of institutions are identified in Table 1.

Modular HRIs frequently incorporate multiple units to achieve flexibility in operations and maintenance.

> Modular incinerators are commonly installed in combinations of two or more units of the same size. This provides for...consistent operating practices and reduces inventory parts requirements. Modular design also provides for easy expansion to accommodate growing waste reduction needs. (55:9)

One of the limitations of modular HRIs is their inefficiency when compared with regional plants. The "...steam generation efficiency from modular plants is generally not equal to the efficiency of the large water wall furnace plants..." (46:E-26). Modular units are seldom "...used to

**TABLE 1**

UTILIZATION OF MODULAR INCINERATORS

(30:104-139)

| Location | Use | Capacity (TPD) | Energy Recovered |
|---|---|---|---|
| New Jersey | Atlantic County Jail | 14 | Steam and Hot Water |
| Sitka, Alaska | Sheldon Jackson College | 25 | Steam |
| London, Ontario | Victoria Hospital | 300 | Steam |
| Miami, Florida | International Airport | 60 | Steam |
| Fort Leonard Wood, Missouri | Army Base | 75 | Steam |

produce the high pressure and temperature steam desired for efficient cogeneration of electric power..." (35:11). Of the 42 modular HRIs (less than or equal to 150 TPD) operating in the United States, only 9 generate electricity. The remaining 33 facilities produce steam for heating applications (24:94-97).

## Environmental Laws and Regulations

Numerous policies and laws govern the construction and operation of HRIs on federal installations. These include the National Environmental Policy Act, the Resource Conservation and Recovery Act, the Clean Air Act, and the Clean Water Act.

National Environmental Policy Act (NEPA). NEPA requires federal agencies to include environmental factors in planning and decision making (43:140). Air Force installations deciding to construct HRIs must follow NEPA requirements. The decision model will address sociopolitical factors pertaining to the construction of a modular HRI. As such, the model may help evaluate the level of effort required to accomplish the NEPA process.

The mechanism for implementing NEPA is the Environmental Impact Analysis Process (EIAP). Under EIAP, evaluation of a proposed action must result in either a categorical exclusion (CATEX), an environmental assessment (EA), or an environmental impact statement (EIS), as shown in Figure 3.

A proposed action can be categorically excluded from further analysis. The Council on Environmental Quality (CEQ) approved a list of CATEX actions that do not require an in-depth environmental analysis. A typical example is minor facility maintenance and repair.

If the proposed action does not qualify for a CATEX, it must undergo an EA. "An EA evaluates the possible long-term environmental consequences and addresses alternative solutions..." (3:18). The EA process involves examining existing environmental conditions, identifying potential impacts of the proposed action and its alternatives, determining the extent of the impacts, determining the cumulative effects of the impacts, and identifying mitigative measures to reduce adverse impacts (42:9). An EA results in either a finding

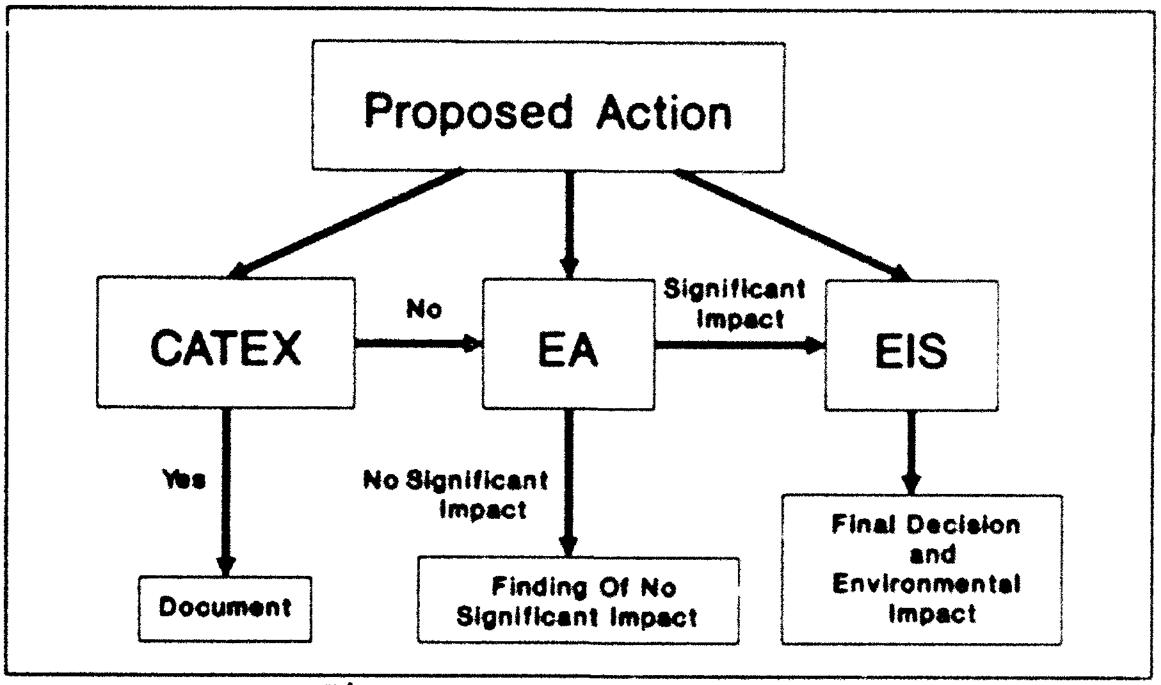


**Figure 3.** The EIAP Process

of no significant impact (FONSI) or initiates the preparation of an EIS. A FONSI "...describes why an action does not have a significant effect on the human environment and thus will not be the subject of an EIS" (15:5). The affected public is informed of the FONSI and given the opportunity to comment before the proponent may proceed with the proposed action (15:5).

If the EA reveals significant environmental impacts, an EIS is necessary. If a proposed action clearly poses significant environmental impacts, proponents may initiate an EIS without performing an EA.

The first step in preparing an EIS is to publish a notice of intent. The range of actions and anticipated impacts are also considered in the scoping process (42:21). Upon completion of the scoping process, a draft EIS is prepared. The draft then follows the process outlined in Figure 4.

> ...NEPA obligates an agency preparing an impact statement to "consult with and obtain the comments of any Federal agency which has jurisdiction by law or special expertise with respect to any environmental impact involved." It also requires that copies of the EIS and the views of commenting agencies be made available to the President, CEQ, and the general public. These requirements of NEPA have yielded an elaborate process involving the circulation of the EIS in draft form, the preparation of review comments by recipients of the "draft EIS," the revision of the draft by the issuing agency and the distribution of a "final EIS." (43:145)

Due to the potential environmental impacts of constructing and operating HRIs (site location, air emissions, handling of MSW, etc.), they do not qualify for a CATEX.

Therefore, HRIs will require either an EA or an EIS in accordance with NEPA (48:C-4). Furthermore, predicting the reaction of individual citizens, interest groups, and local agencies to a HRI proposal (sociopolitical acceptability) may help evaluate the level of Air Force resources necessary for the NEPA process. For example, low sociopolitical acceptance may indicate the potential for increased resistance in issuing a FONSI (for an EA) on the proposed HRI. Low sociopolitical acceptance may also signify greater opposition in the scoping process (for an EIS). Both would

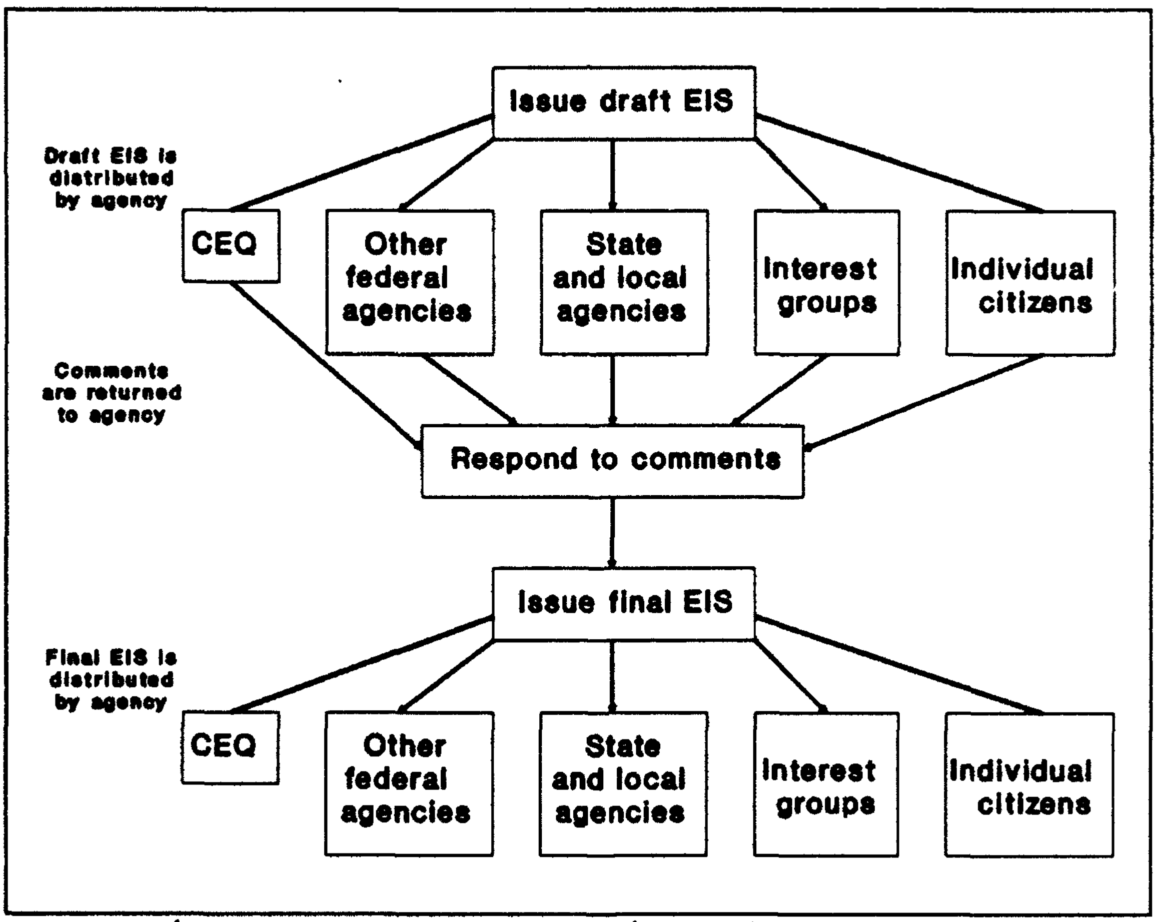


**Figure 4.** Process of Review and Comment on a Draft EIS (43:145)

result in increasing the expenditure of Air Force time, money, and manpower required to fulfill NEPA requirements.

Resource Conservation and Recovery Act (RCRA). RCRA governs both non-hazardous and hazardous solid wastes. "It focuses on, but is not exclusively limited to, land disposal of these wastes" (26:104). Since the byproduct of incineration (ash) is classified as a solid waste, RCRA applies. The classification (hazardous or non-hazardous) of the ash byproducts from the incineration of MSW is a key issue. Subtitle C of RCRA addresses hazardous wastes and Subtitle D pertains to non-hazardous solid wastes.

A hazardous waste is a solid waste that exhibits characteristics of reactivity, ignitability, corrosivity, or toxicity, or is listed in the CFR, Title 40, Part 261, Sections 30-33 (72:44-63). Since the MSW stream may contain various hazardous substances, it is important to analyze the characteristics of the residues from the HRI combustion process.

Combustion in a HRI produces both bottom and fly ash. Bottom ash is the heavy ash that falls to the bottom of the combustion chamber. Fly ash is a very fine particulate that travels through the furnace stack with the hot combustion gases (59:5-3).

Two potential problems associated with combustion ash are toxicity and corrosivity. Ash toxicity is partly a function of the concentration of heavy metals, predominantly lead, cadmium, and mercury (5:5; 22:8). Compared with bottom ash, fly ash normally contains higher levels of heavy metals (59:5-3). Table 2 lists the maximum allowable concentrations for heavy metals in leachate. The corrosivity characteristics of bottom ash and fly ash also differ. "Bottom ash is alkaline, while fly ash is acidic" (59:5-3).

At some refuse burning plants, the ash byproduct exceeds the toxicity or corrosivity limits that RCRA associates with a hazardous waste. However, for the purposes of waste identification, RCRA regards MSW as non-hazardous under the household exclusion policy (72:32-33).

> ...[Ash] from municipal incinerators is exempt from subtitle C regulation under RCRA. Section 3001(i) of the law specifically excludes waste combustors, and according to the courts, the ash they produce, from Federal hazardous waste regulation. As a result, ash is an unregulated waste under current law. (11:4)

**TABLE 2**

HEAVY METALS CONCENTRATION LIMITS

(72:47)

| Contaminant | Maximum Concentration (mg/L) |
|---|---|
| Arsenic | 5.0 |
| Barium | 100.0 |
| Cadmium | 1.0 |
| Chromium | 5.0 |
| Lead | 5.0 |
| Mercury | 0.2 |
| Selenium | 1.0 |
| Silver | 5.0 |

In fact, there are presently no federal RCRA permitting requirements for MSW incinerator operations (63).

Future action at the federal level concerning the categorization of MSW incinerator ash (as hazardous or non-hazardous) may be slow. Although the issue was proposed during the proceedings of the Clean Air Act (CAA) Amendments of 1990, Congress decided to delay addressing this issue until the next reauthorization of RCRA (10:3). Section 306 (Ash Management and Disposal) of the CAA Amendments of 1990 stipulates the following:

> For a period of 2 years after the date of enactment of the Clean Air Act Amendments of 1990 [November 15, 1990 through November 15, 1992], ash from solid waste incineration units burning municipal waste shall not be regulated by the Administrator of the Environmental Protection Agency pursuant to section 3001 of the Solid Waste Disposal Act. (56:2)

The court system has upheld the categorization of ash as non-hazardous. In a recent lawsuit the Environmental Defense Fund (EDF) attempted to sue two incinerator operators, Wheelabrator Incorporated and the City of Chicago. The EDF charged the operators with hazardous waste generation and mishandling hazardous waste, violating RCRA Subtitle C. However, two judges dismissed the suit, finding the ash exempt from Subtitle C under RCRA (11:4).

Some states control ash disposal by regulating it as a special waste. For example, lead levels in the ash at the Dayton Montgomery County North Incinerator (Dayton, Ohio) averaged 8 mg/L during 1989 (5:11). The state of Ohio has separate guidance to deal with heavy metals. This guidance requires toxicity testing for heavy metals prior to disposal in landfills. If results of the samples exceed established limits, the ash must go to a hazardous waste disposal facility. An alternative is to treat the ash to render it non-hazardous (59:5-7). Since Ohio's lead standard is 5 mg/L, the Dayton Montgomery County North Incinerator encapsulates its incinerator ash (see section on pollution control of ash emissions) prior to disposal in a landfill (59:5-4; 13).

Non-hazardous solid wastes are regulated in Subtitle D of RCRA. Since MSW is currently categorized as non-hazardous, Subtitle D of RCRA governs the operations of HRIs. It identifies that design and operation of MSW incinerators adhere to "federal regulations and guidelines pertaining to the handling of solid wastes...contained in Title 40, Chapter I, Subchapter I - Solid Wastes, Parts 240-280 of the CFR" (51:59). Specifically, Part 240 addresses the thermal processing of solid wastes. These guidelines include requirements for solid wastes accepted, solid wastes excluded, site selection, general design, water quality, air quality, vectors, aesthetics, residue, safety, general operations, and records (71:252).

Subtitle D of RCRA also governs MSW disposal in landfills. The latest municipal landfill regulations promulgated by the USEPA (40 CFR, Part 258) could significantly impact future MSW disposal costs. These regulations include location restrictions, operating requirements, design standards, groundwater monitoring and corrective action requirements, closure and post-closure care, and financial assurance measures. Monitoring closed landfills for 30 years, as well as groundwater and methane gas monitoring requirements for active landfills, are examples of potential cost increasing measures resulting from the new requirements (65:1-2). These increased costs might reduce the number of available landfills as well as improve the economic viability of incinerating MSW versus landfilling.

Clean Air Act (CAA). When addressing the environmental compliance of HRIs, it is necessary to consider the CAA. The CAA addresses the nation's air pollution problems. It is a conglomeration of legislation beginning in 1955 with the passage of the Air Pollution Control Act and continuing with the passage of the CAA Amendments of 1990. It establishes air quality standards and sets pollution emissions restrictions on various activities. The 1970, 1977, and 1990 Amendments to the CAA, and the latest New Source Performance Standards impact HRIs.

CAA Amendments of 1970. The CAA Amendments of 1970 established National Ambient Air Quality Standards (NAAQS). The NAAQS "...centered on a small set of compounds, called criteria pollutants, that have been identified as contributors to both sulfurous and photochemical smog problems" (34:271). Table 3 shows the allowable levels of the six criteria pollutants governed by the NAAQS. HRI emissions normally contain all of the criteria pollutants except ozone.

**TABLE 3**

NATIONAL AMBIENT AIR QUALITY STANDARDS
(FOR CRITERIA POLLUTANTS)

(34:273)

| Pollutant | Averaging Time | Primary Standard |
|---|---|---|
| Carbon Monoxide | 8 hour<br>1 hour | 10 $mg/m^3$ (9 ppm)<br>40 $mg/m^3$ (35 ppm) |
| Nitrogen Dioxide | Annual | 100 $\mu g/m^3$<br>(0.053 ppm) |
| Ozone | 1 hour | 235 $\mu g/m^3$<br>(0.12 ppm) |
| Sulfur Dioxide | Annual<br><br>24 hour | 80 $\mu g/m^3$<br>(0 03 ppm)<br>365 $\mu g/m^3$<br>(0.14 ppm) |
| Lead | 3 months | 1.5 $\mu g/m^3$ |
| Particulates<br>(dia. $\leq$ 10 $\mu m$) | Annual<br>24 hours | 50 $\mu g/m^3$<br>150 $\mu g/m^3$ |

The Clean Air Act Amendments of 1970 also identified New Source Performance Standards (NSPS). "These standards were to control new stationary sources categorized by the [EPA] administrator as contributing significantly to air pollution" (43:125). Examples of these sources are portland cement plants, nitric acid plants, and municipal incinerators (43:125). This was the first regulation to specifically address air pollutants from plants burning MSW. Originally, the 1970 NSPS for incinerators only regulated particulate emissions from facilities burning more than 50 tons of refuse per day (62:48).

CAA Amendments of 1977. The CAA Amendments of 1977 established emission offsets for areas that did not attain the NAAQS (nonattainment areas).

> The amendments required that a significant new source locating in a nonattainment area had to meet strict emission reduction requirements developed by the EPA administrator. In addition, discharges from the new sources had to be more than offset by reductions in emissions from other sources in the region. After the "emission offsets" were applied, the net effect had to be reasonable progress toward meeting the NAAQS in the region. (43:128)

Therefore, locating proposed HRIs in nonattainment areas must be coupled with a reduction in existing pollution levels within the region. Appendix B identifies the major Air Force installations located in nonattainment areas.

The CAA Amendments of 1977 also addressed regions that were cleaner than ambient standards. In order to control the deterioration in these regions, the amendments established "...the concept of prevention of significant deterioration (PSD) in attainment areas" (34:278). There are three classes of PSD areas.

> Class I areas include National Parks and Wilderness Areas, and almost no increase in pollution is allowed. Moderate deterioration is allowed in Class II areas, and even greater amounts are allowed in Class III areas. (34:278)

Each state has the power to classify which areas fall under Class II and III categories (43:128).

CAA Amendments of 1990. A potential impact of the CAA Amendments of 1990 on HRIs is the new Air Toxics Program. This program requires the EPA to "...set standards for at least 40 toxic pollutants within two years after enactment" (8:52) and to regulate 189 toxic pollutants by the year 2000. The law requires that EPA set emission standards for new and existing sources of air toxics, based on maximum available control technology (8:51). The EPA speculates that less than five percent of the 189 hazardous air pollutants will impact HRIs. Currently lead, cadmium, mercury, dioxins, and furans emissions are of primary concern to regulators (44). Therefore, installations proposing to construct a HRI must reference the latest NSPS to determine emission levels for these substances.

Title V of the CAA Amendments of 1990 outlines permitting requirements. HRIs must obtain air emissions operating permits within three years following the promulgation of revised performance standards for new and existing MSW combustors. These permits are valid for a period of up to five years from the date of issuance (39:13-14).

Current NSPS. The NSPS evolved from regulating strictly particulates to also regulating emissions of carbon monoxide, heavy metals, sulfur dioxide, nitrogen oxides, hydrogen chloride, chlorinated dibenzo-p-dioxins (also referred in this text as CDD and dioxins), and chlorinated dibenzofurans (also called CDF and furans) (62:48). The current NSPS identify certain air emission requirements by incinerator type and others by incinerator size. An example of requirements established by incinerator type are the carbon monoxide (CO) standards listed in Table 4. An example of requirements established by incinerator size are

**TABLE 4**

CO EMISSION LIMITS BY INCINERATOR TYPE
(AT 7% OXYGEN, DRY BASIS)

(22:8)

| Incinerator Type | Averaging Time (hr) | CO Level (ppmv) * |
|---|---|---|
| Modular starved & excess air | 4 | 50 |
| Mass burn waterwall & refractory | 4 | 100 |
| Mass burn rotary waterwall | 24 | 100 |
| Fluidized-bed combustion | 4 | 100 |
| Refuse-derived fuel stokers | 24 | 150 |
| Coal/RDF mixed fuel | 4 | 150 |

* ppmv represents parts per million by volume

identified in Table 5. The NSPS define small HRIs as combustion units with design capacities of less than or equal to 250 TPD and large units with design capacities greater than 250 TPD.

The CAA Amendments of 1990 specified that the NSPS for large facilities be revised by November 15, 1991 (66:5488). However, the USEPA did not meet this deadline. Proposed standards for large facilities are scheduled for final approval in late 1992 (44). In addition, the 1990 CAA Amendments specified that proposed standards for small incinerators be finalized by November 15, 1992 (66:5488). Following the establishment of these standards, the

> EPA must review, and revise if appropriate, the performance standards every five years. The updated standards must be based on "methods and technologies for removal or destruction of pollutants before, during, or after combustion." (39:13)

**TABLE 5**

MUNICIPAL WASTE COMBUSTION EMISSION STANDARDS *

([a]6:1325; [b]66:5490)

| Capacity (TPD) | ≤250 | >250 |
|---|---|---|
| **Metal Emissions** | | |
| Particulate Matter milligrams per dry standard cubic meter (mg/dscm) | 34[a] | 34[a] |
| Opacity (%) ** | 10[a] | 10[a] |
| **Organic Emissions** | | |
| Chlorinated Dibenzo-p-dioxins & Dibenzofurans (CDD/CDF), nanograms per dry standard cubic meter (ng/dscm) | 75[a] | 30[b] |
| **Acid Gas Emissions** % reduction or (emissions - ppmv) | | |
| Hydrogen Chloride (HCl) | 80[a] (25)[a] | 95[a] (25)[a] |
| Sulfur Dioxide ($SO_2$) *** | 50[a] (30)[a] | 80[b] (30)[a] |
| Nitrogen Oxides ($NO_x$) *** | None[a] | (180)[b] |

* All emission levels are at 7% $O_2$, dry basis
** 6-minute averaging time
*** 24-hour averaging time

<u>Clean Water Act (CWA)</u>. The CWA addresses the nation's water pollution problems. It is a collection of legislation beginning in 1948 with the passage of the Water Pollution Control Act and continuing with the passage of the CWA of 1977. In particular, the 1972 Federal Water Pollution

Control Act Amendments instituted the National Pollutant Discharge Elimination System (NPDES) (4^:112-113).

NPDES established a permitting system for point source water polluters. A NPDES permit provides the right to pollute within specified limits. "Any industrial activity discharging [wastewater] into [a] stream, river, or other waterway must have a current, valid NPDES permit" (26 34).

Air Force bases either discharge wastewater into surrounding bodies of water (via a NPDES-permitted base wastewater treatment plant) or send it to regional publicly owned treatment works (POTWs). POTWs may issue pretreatment permits to the base, specifying acceptable effluent emission levels.

Various HRI operations produce wastewater. Water used to quench the ash may require treatment, while equipment and facility cleaning will generate wastewater discharges. The physical layout of the HRI may also contribute to the contamination of stormwater runoff. Consequently, it is necessary to consider wastewater during the design of a HRI. Providing adequate drainage for stormwater runoff and ensuring that MSW storage areas are enclosed are examples of measures that can be included in the design of the facility to minimize contamination.

Air Force bases deciding to construct a HRI must ensure compliance with either NPDES or pretreatment permit requirements. "In most cases, wastewater discharges can be treated by settling, clarification, and/or other methods of pretreatment at the MSW combustion facility" (51:63).

MSW incinerator cost estimating models typically do not identify these conventional methods of treating wastewater as a separate controlling cost factor. For example, the Technological and Economic Evaluation of Municipal Solid Waste Incineration study, sponsored by the University of Illinois Center for Solid Waste Management and Research, considers three factors for economic evaluation of MSW incinerators. They are "...the capital cost of MSW incinerators, the capital cost of the related air pollution control equipment, and the annualized operating costs of the air pollution control equipment" (51:65). Costs associated with achieving water quality compliance should be considered part of the capital cost of the MSW incinerator, not a separate factor.

Summary of Environmental Laws and Regulations. The environmental laws and regulations governing HRI construction and operation reviewed in this research include the National Environmental Policy Act, the Resource Conservation and Recovery Act, the Clean Air Act, and the Clean Water Act. Although new HRIs must comply with all of these laws, current literature indicates that the New Source Performance Standards under the Clean Air Act will have a significant effect in determining the actual construction and operating costs of a HRI. The Resource Conservation and Recovery Act has the potential (due to the ash categorization issue) to have a major impact on operating costs. The literature also reveals that modeling costs associated with achieving water quality compliance (in accordance with the Clean Water Act) may be categorized as part of the capital cost of the MSW incinerator.

## Pollution Control Technologies

Pollution control techniques satisfy environmental compliance requirements and have a large impact on HRI capital and operating costs. Both ash and air emissions require pollution control consideration.

Ash Control Technology. Ash emissions from HRI operations may present a problem due to the concentration of heavy metals following the incineration process. These emissions include fly ash, bottom ash, and a mixture of bottom and fly ash (combined ash).

One innovative technique for handling the heavy metals in the ash is the addition of a cement stabilizing agent. This fixes the metals within the cement and ash matrix and prevents leaching when buried in a landfill (13).

Utilization of stabilized ash is also possible. A plant in Alpena, Michigan produced concrete blocks from a mixture of combined ash and portland cement. These blocks were used to construct an artificial reef in Long Island Sound, New York (50:242-244). Another example is the nation's first building constructed of masonry blocks made from MSW ash, built in early 1991 at the State University of

New York, Stony Brook. These blocks tested stronger than traditional cinder blocks, as determined by the American Society for Testing Materials (75:74). In each of these cases, observations showed no adverse environmental impacts in using the ash containing materials.

Researchers in Sweden are also testing the capability of using bottom ash as fill material in road construction. Thus far, results reveal that the bearing capacity of bottom ash compares well with natural aggregate. Furthermore, the researchers found no heavy metal leachate problems when only bottom ash was used as fill material (23:271,278).

<u>Air Emissions Control Technologies</u>. Current NSPS (and any future air emissions standards issued in accordance with the CAA Amendments of 1990) are technology-based (66:5490). Table 6 identifies the technologies used to establish current pollution emission levels for new municipal waste combustors.

The seven air pollution control technologies typically used in MSW incinerators are cyclones, electrostatic precipitators, fabric filters/baghouses, wet scrubbers, spray dryers/dry sorbent injection systems, low nitrogen oxides ($NO_x$) combustion, and selective non-catalytic reduction.

<u>Cyclones</u>. Cyclones are the most common particulate removal devices for large particles. Particles leaving the combustion chamber enter the top of the conical-shaped cyclone. Centrifugal force from the moving gases causes large particles to collide with the sides of the cyclone.

Gravity then causes the particles to fall into a hopper. Particulate removal efficiencies for particles larger than five micrometers can exceed 90 percent (34:351). However, typical efficiencies for small particle removal vary between 30 and 80 percent (55:43). Due to their low efficiencies at small particle removal

> ...cyclones are used in boiler and incinerator plants to remove large, coarse, abrasive particles that could damage downstream fabric filters, and to improve electrostatic precipitator and scrubber efficiency by allowing more uniform inlet flow. (55:44)

Therefore, cyclones may be installed to increase the operational life and efficiency of other particulate removal

**TABLE 6**

TECHNOLOGY BASIS FOR CONTROL OF EMISSIONS IN NEW MUNICIPAL WASTE COMBUSTORS

(66:5490)

| Emissions | Technology Basis |
|---|---|
| Organics | Good combustion practices (*), spray dryer, and fabric filter |
| Metals | Fabric filter |
| Acid Gases | Spray dryer and fabric filter |
| Nitrogen Oxides | Selective noncatalytic reduction |

* Includes operating within CO emission limits identified in Table 4, within 110% of the maximum load level demonstrated during the most recent dioxin and furan performance test, and no more than 30°F above the maximum particulate matter control device inlet temperature demonstrated during dioxin/furan performance test.

devices, but are not normally used as the only air emissions control device for a facility.

Electrostatic Precipitators. Electrostatic precipitators (ESPs) operate by removing very fine particulate matter (fly ash) from the combustion gases leaving the incinerator (34:352). Hundreds of charged metal plates are arranged parallel to each other in a collection tower. As the incinerator gases pass through these plates, the fly ash particles become charged, and move to the charged metal. Mechanical vibrations remove the fly ash from the plates and into a collection basin (34:352).

An electrostatic precipitator's "...efficiency ranges from fair to excellent in the removal of particulate matter (including most metals), depending on the size and design of the equipment and the flue-gas flow" (22:10). Typical efficiencies are between 90 to 96 percent (55:43). Alone, electrostatic precipitators do not provide sufficient acid gas or organic control. Therefore, additional pollution control devices (such as spray dryers or dry sorbent injection systems) are normally required to meet current emission standards.

Fabric Filters/Baghouses. Fabric filters/baghouses are another air pollution control device _n use today.

> Simply stated, fabric filters allow removal of total and fine particulates and, in some cases, small amounts of heavy metals, dioxins, and acid gases that adhere to fly ash, by forcing the air through a specially designed fabric. The parti-

cles collected on the fabric, in turn, form a cake that acts as an additional layer through which air is forced. (62:49)

Fabric filters are slightly more efficient than electrostatic precipitators for removing particulates. Typical particulate removal efficiencies are between 97 to 99 percent (55:43). Compared with electrostatic precipitators, fabric filters "...represent the preferred air pollution control technology in the United States" (62:49).

Although fabric filters provide emission control for a wide variety of pollutants, they usually operate in conjunction with other pollution control devices. Alone they are not capable of providing adequate acid gas removal to meet standards. Therefore, they normally follow a scrubber or dry sorbent injection system (22:10).

<u>Wet Scrubbers</u>. Wet scrubbers utilize a wet alkaline mixture, usually containing lime or limestone, to neutralize combustion gases. The solution adsorbs acid gases and particulates and forms a sludge. The sludge falls to the bottom of the scrubber where it is collected for future treatment (22:11; 34:350; 62:49).

Wet scrubbers can help control particulates and organics (dioxins and furans), but their primary purpose is to neutralize acid gases.

> Wet scrubbing systems have demonstrated their ability to meet the standard removal efficiencies of 90 percent for hydrogen chloride and hydrogen fluoride and 70 percent for sulfur dioxide, with some wet-scrubbing systems demonstrating a removal efficiency for sulfur dioxide in excess of 95 percent. (62:49)

Although wet scrubbers are popular in coal-fired power plants, they are "..the least popular of the scrubbing systems for municipal solid waste incinerators..." (62:49). Wet scrubbers are expensive, require large amounts of water, and produce a great deal of sludge. They are also susceptible to corrosion, scaling, and plugging (34:350; 62:49).

Spray Dryers/Dry Sorbent Injection Systems. A fourth method of air pollution control is either a spray dryer or a dry sorbent injection system (called dry scrubbers). In the spray dryer, a slaked lime slurry is injected into the combustion exhaust gases to neutralize acid gases. The water in the slurry evaporates in the process. The dry sorbent injection system is similar to the spray dryer; however, the slurry is replaced with a dry alkaline sorbent. Any acid gases that are present react with the alkaline material to produce a neutral salt. The salt collects at the bottom of the scrubber and the cleansed gases move out of the incinerator stack (18:4.116-4.117; 22:13-15; 62:49).

Spray dryers can remove more than 90 percent hydrogen chloride (HCl) and more than 70 percent sulfur dioxide ($SO_2$). Dry sorbent injection systems normally remove more than 50 percent HCl and up to 50 percent $SO_2$. Both systems provide a degree of organics (dioxins and furans) removal capability (22:18). In addition, particulate removal efficiencies for these devices range from 80 to 95 percent (55:43). Typical incinerator operations place fabric filters or electrostatic precipitators downstream of spray dryers or dry sorbent injectors to enhance particulate control (22:13-14).

Low $NO_x$ Combustion. Fuels burning at high temperatures normally release nitrogen, which oxidizes to form $NO_x$, a primary contributor to photochemical smog (ozone). A method of controlling $NO_x$ emissions from HRIs is low $NO_x$ combustion. One low $NO_x$ combustion method uses the starved-air technology, which was discussed earlier.

> In the first stage of combustion, the fuel starts burning in an air-starved environment, causing the fuel-bound nitrogen to be released as nitrogen gas, $N_2$, rather than $NO_x$. The following stage introduces more air to allow complete combustion of the fuel to take place. Potential $NO_x$ reductions of 45-60 percent [are] likely. (34:349)

Selective Non-Catalytic Reduction (SNCR). Another method of $NO_x$ control is SNCR. The SNCR process injects ammonia or urea directly into the combustion chamber to control $NO_x$. At a temperature of 1600 to 2000°F, the ammonia reacts with $NO_x$ to form nitrogen gas. $NO_x$ removal efficiencies normally range from 40 to 75 percent using SNCR technology (22:21).

Summary of Pollution Control Technologies. The literature review identified air pollution control as a significant determinant of HRI costs (in order to meet NSPS) and the potential for ash control to be a major determinant of operating costs (due to the ash categorization issue under RCRA). The literature also reveals that modeling costs associated with achieving water quality compliance (in accordance with the Clean Water Act) may be categorized as part of the capital cost of the MSW incinerator. The literature review of pollution control technologies focused on reducing ash and air emissions from HRIs. Encapsulation of the ash in a cement matrix is the primary means of controlling ash emissions. This matrix can be used in construction or deposited into a landfill. The five primary air pollutants from MSW incineration are particulates, acid gases, dioxins/furans, nitrogen oxides, and carbon monoxide. Devices and processes currently used with HRIs to control emissions are cyclones, electrostatic precipitators, fabric filters/baghouses, wet scrubbers, spray dryers/dry sorbent injection systems, low $NO_x$ combustion, and selective non-catalytic reduction. The most commonly used air pollution control devices for modular HRIs are electrostatic precipitators and fabric filters/baghouses for particulates, and wet scrubbers and dry scrubbers for acid gas control (24:94-99).

## Economic Analysis Techniques

Two techniques useful in evaluating the economic viability of HRIs are simple payback and life cycle cost analysis.

Simple Payback Analysis. Simple payback is a method of economic analysis that determines the length of time to recover initial capital investment. It "...is a measure of how long it takes you just to break even..." (54:66).

The payback in years is found by:

$$SPB = \frac{\Delta I}{\Delta S} \tag{1}$$

where: $\Delta I$ = the difference between the capital costs of two alternatives

$\Delta S$ = the difference between the annual costs of two alternatives

SPB = simple payback in years (28:56-57)

There are several disadvantages to using simple payback. It does not take into account the life span of the alternative. For example, an alternative with a payback of eight years might not be acceptable. However, if this alternative has a project life of 25 years, the payback may be desirable. Simple payback also does not take into account the time value of money. Therefore, it is not the actual payback time, but a relative figure used for comparison with other alternatives. Simple payback is "...limited because the project with the shortest payback is not necessarily the project with the highest return..." (54:66).

Despite the disadvantages, there are numerous benefits to using simple payback analysis. The method is very easy to use and understand. "Many plant managers, building owners, developers, and boards of trustees prefer to use simple payback" (28:57). Simple payback does not require an estimate of future interest rates, inflation rates, and life spans of the alternatives. This is an advantage in a relatively uncertain environment. Furthermore, as the level of certainty improves, simple payback "...can be converted to other methods such as discounted payback, or return on investment..." (28:57) by including estimated interest rates, inflation rates, and life spans of the alternatives.

Life Cycle Cost (LCC) Analysis. LCC analysis sums the present worth of all discounted project costs and benefits, for the life of the project. The following equation determines the LCC of a proposed alternative:

$$LCC = \sum_{i=0}^{n} \frac{C_i}{(1+d)^i} \qquad (2)$$

where: i = current time period

n = total number of time periods

C = costs (benefits are negative)

d = discount rate

LCC = life cycle cost of alternative (54:64)

The major disadvantage of LCC is the inability to accurately forecast future costs and benefits. However, LCC analysis "...is a more efficient approach than payback in evaluating capital alternatives because it takes into account all costs over the life of a project rather than first costs only" (40:76). Furthermore, according to the Life-Cycle Cost Manual for the Federal Energy Management Program,

> The life-cycle costing methods and procedures set forth in 10 C.F.R., Part 436, Subpart A, are to be followed by all Federal agencies, unless specifically exempted, in evaluating the cost effectiveness of potential energy conservation and renewable energy investments in federally owned and leased buildings. (54:v)

Summary of Economic Analysis Techniques. This section reviewed the economic analysis techniques of simple payback and life-cycle costing for evaluating HRIs. The literature showed that federal regulations require using the life-cycle cost technique for determining the economic viability of HRIs.

## Sociopolitical Concerns

With the increasing emphasis on environmental problems and concern over long-term health effects from pollution, the siting, construction and operation of a HRI facility presents many challenges. This section discusses the sociopolitical concerns that may impact HRI construction and identifies various mitigative measures to minimize negative effects. It concludes with a review of the various methods of informing the public and identifies different techniques for involving the public in discussions.

Sociopolitical Issues. Four issues that could challenge HRI development include health risk, siting/operation, multimedia pollution, and waste reduction issues.

Health Risk Issues. An important issue when considering the construction of a HRI is the potential health risk to those within the vicinity of the proposed site.

People's perceptions concerning the risks of incineration are crucial to HRI acceptance.

> If they perceive a facility is safe, then it is possible to talk about other issues. If they perceive a

> project poses a genuine risk to health or safety, then everything else is nonnegotiable. (73:84)

The primary concern is whether the proposed HRI will operate safely (pose an acceptable health risk). "...The EPA attempts to control [individual] exposure to toxics to levels that will pose lifetime risks of on the order of one in $10^{-7}$ to $10^{-4}$..." (34:192). The EPA identifies these levels by performing a health risk assessment (31:36). Research by the EPA shows that emissions from well-designed/operated HRIs pose very low health risks (61:1812).

While scientists and engineers use probabilities to quantify risks, "the public, in contrast, views risk hazards with 'intuitive' risk judgements...such as whether the risk is voluntary, dreaded, or controllable" (73:66).

> The methodology of the health risk assessment is so well understood by its practitioners that they feel very comfortable with upper bound results expressed in risks of $10^{-6}$. They forget the admonition in Crouch and Wilson's pioneering paper on risk assessment: "No one is born with an intuitive understanding of one in a million. It is an acquisition that can only be made by comparison." (31:36)

A method of mitigating public concerns regarding health risk issues is to address the public using simple risk comparisons. For example, comparing the risks from incinerator emissions versus the risks of landfill leachate. Another example is arguing "...that not building a facility will mean a risk level substantially greater than if such a facility comes on-line" (73:69). This may be the case if a new facility's air emissions would be lower than the existing facility's air emissions.

While employing this mitigative method, it is important to avoid certain risk comparison pitfalls. Three of these pitfalls are

1) Comparisons between voluntary (e.g., driving, smoking, drinking diet beverages) and involuntary (e.g., waste management facility) risks;

2) Messages that trivialize risks (e.g., living near a facility is no more dangerous than eating peanut butter); and

3) Comparisons between non-substitutable risks (e.g., flying in an airplane and living near a landfill). (73:68)

Since people are skeptical of risk comparisons, they must be made in ways that are acceptable (73:68). The public may feel that no risk is acceptable, no matter how small. Trying to trivialize the risk or explain it away can serve to alienate the public rather than gain their support.

<u>Siting/Operation Issues</u>. A proposal to construct a new HRI can elicit a negative response from nearby residents. This response is known as the "Not In My Backyard" (NIMBY) syndrome. The NIMBY syndrome is a reaction triggered by several potential concerns of the public.

One concern may be the local residents' fear of decreased property values which could significantly hamper the growth of the community and reduce its tax base. A mitigation method could be a study of the impact existing WTE throughout the United States have had on residential property values.

Another concern is the undesirable image associated with siting an incinerator in the local area (61:1812).

"People often have difficulty accepting assurances that modern solid waste facilities do not look like the old 'dump'" (73:91). The stigma attached to incineration is that of a dirty, noisy, foul smelling operation. Several mitigative methods are available to control the perception of this negative stereotype. Dust control measures may include operational procedures such as wetting the fly ash and maintaining good housekeeping practices. Also, a "hot-line" to the facility can provide an avenue to address dust control problems. To control noise, the best and cheapest alternative is to incorporate noise control into the design of the facility. Other alternatives include installing soundproofing equipment, rerouting traffic (refuse trucks), or modifying operating hours (73:90). Other measures may include taking an interested group to an existing WTE facility to show them that these facilities have few odor and litter problems (73:88).

> Arrangements can even be made to let neighbors of a proposed facility talk with neighbors of an existing facility; people are more likely to believe others in the actual situation than 'official' statements. (73:88)

A final reason for the NIMBY syndrome is the public's "...general distrust of government and industry" (61:1812) to adequately address their concerns. This is often mitigated by providing the affected public with a degree of control. For example, representation on the body that governs facility operations provides a means of influence in the decision-making process. Providing the public direct access to facility management and the capability to shut down the facility can create the means to handle safety issues. Although this may be possible at privately or municipally owned incinerators, it is necessary to recognize that there are limits in the level of control that an Air Force installation can yield to the public (73:86).

Multimedia Pollution Issues. It is important to consider a region's air and water resources when proposing to construct a HRI.

The most visible pollution problem associated with HRIs is air emissions. The best method of mitigating this problem is by presorting the MSW and installing appropriate air pollution control equipment. Furthermore, establishing and publicizing a record of compliance with federal, state, and local air requirements promotes credibility (73:88). It is important to realize that the amount of effort to mitigate air pollution issues is directly related to the location of the proposed facility. For example, communities in non-attainment areas and PSD areas may be very sensitive to the impact of HRIs on air quality and will require more extensive mitigation measures.

Water pollution from HRI operations may be another concern of the affected public. The community's source of water (groundwater or surface water), and the perceived impact of HRI operations on that source, may influence their degree of concern. A way to mitigate water pollution problems is to collect and treat process water and storm water runoff from areas likely to be contaminated (such as MSW holding locations and incinerator ash piles). Conducting and publicizing a pollutant monitoring program should educate the public and provide a sense of security. Again, a history of compliance with federal, state, and local water regulations builds credibility with the public (73:88-89).

Waste Reduction Issues. There are currently two diametrically opposing views regarding the relationship between recycling and incineration. Some people see recycling as completely complementary to HRIs. Others assert that "...burning and recycling are fundamentally incompatible since most of the material that can be burned can also be recycled" (14:29). Communities that have an effective recycling program in place normally enjoy some added benefits with respect to HRIs. The Camden WTE facility illustrates some of these advantages (57:14).

> Because of recycling...the Camden WTE plant is about 350 tons per day smaller than otherwise would have been necessary (and significantly less costly to build). ...[Recycling] will increase the BTU value of the fuel, and...reduce several types of waste that can cause damage to the boilers and lower efficiency. (57:14-15)

However, the recycling activity has also had an observed negative impact on the WTE industry. Recycling activities have allegedly played a part in stalling several WTE projects (30:142).

> Increased recycling activity across the U.S. has caused many communities to reflect upon their MSW strategies. In some cases, decision-makers are reassessing the size of planned [WTE facilities]; in other cases, the volatility of the political environment makes it easier for elected officials <u>not</u> to make important immediate

decisions regarding their [WTE facility] or other management options. (30:101)

The most effective way to mitigate waste reduction concerns "...is to have an effective waste reduction and recycling program in place in the community before beginning the siting process" (73:91). Developing and publicizing a solid waste management plan that maximizes source reduction and recycling (prior to disposal) can lessen public anxiety about the effects of a HRI on recycling efforts, and provides a more accurate estimate of MSW availability to ensure a minimum sized facility to meet the incineration needs.

Methods of Public Involvement. There are two major ways to involve the public in the decision-making process. One is through informative methods and the other is through participative methods. Informative methods are used to disseminate information to the affected public. They include actions such as briefings and news releases. Participative methods solicit feedback from the affected public to assist in the decision-making process (73:41). They include actions such as meetings and hearings. Tables 7 and 8 identify the features, advantages, and disadvantages of various public information and participation techniques, respectively.

Summary of Sociopolitical Issues. Health risks, siting/operations, multimedia pollution, and waste reduction issues are the major sociopolitical concerns surrounding HRI construction and operation. This section discussed these concerns and identified various mitigative measures to minimize their negative effects. It also identified informative and participative methods of involving the public in the HRI decision-making process.

Summary

This chapter reviewed modular HRI technology, environmental laws and regulations governing HRI operation, current HRI emission control technologies, economic analyses techniques, and the sociopolitical factors, mitigative measures, and public involvement techniques associated with constructing a HRI.

The two modular HRI technologies identified were the starved-air and excess-air designs. Most HRIs operate with starved-air technology.

Applicable environmental laws and regulations included the National Environmental Policy Act, the Resource Conservation and Recovery Act, the Clean Air Act, and the Clean Water Act. The most significant federal rules impacting HRI costs are the New Source Performance Standards (which must be reviewed/revised every five years) under the Clean Air Act, which drive the selection of air pollution control devices. In addition, the Resource Conservation and Recovery Act has the potential to significantly impact HRI operating costs (if ash is categorized as a solid waste in the future).

There are numerous pollution control technologies for containing and reducing emissions from incinerators. Encapsulation in a cement matrix is a common means of controlling incinerator ash. This matrix can be used in construction or deposited into a landfill. For air emissions, the five pollutants of concern are particulates, acid gases, dioxins/furans, nitrogen oxides, and carbon monoxide. This chapter contains a review of the various methods and devices currently used on incinerators to control these emissions. The most commonly used air pollution control devices for modular HRIs are electrostatic precipitators and fabric filters/baghouses for particulates, and wet scrubbers and dry scrubbers (spray dryers and dry sorbent injection systems) for acid gas control (24:94-99).

The two economic analysis techniques reviewed were simple payback and life-cycle costing. Federal regulations require using the life-cycle cost technique to evaluate the economic feasibility of federal construction projects that have the potential for energy conservation (54:v). Therefore, life-cycle costing should be used for evaluating HRIs.

The important sociopolitical issues involved in HRIs are health risks, siting/operations, multimedia pollution issues, and waste reduction issues. The literature review listed various mitigative measures to address concerns relating to each of these issues. This review also identified informative and participative methods of involving the public in the HRI decision-making process.

TABLE 7

PUBLIC INFORMATION TECHNIQUES

(73:43)

| Technique | Features | Advantages | Disadvantages |
|---|---|---|---|
| Briefings | Personal visit or phone call to key officials or group leaders to announce a decision, provide background information, or answer questions. | Provide background information. Determine reactions before an issue "goes public." Alert key people to issues that may affect them. | Requires time. |
| Feature stories | In-depth story about the siting study in newspapers or on radio and television. | Provide detailed information to stimulate interest in the siting study, particularly at key junctures such as evaluating alternative sites or selecting a preferred site. Often used prior to public meetings to stimulate interest. | Newspaper will present the story as editor sees fit—project proponent has no control over how the story is presented, except to provide full information. |
| Mailing out key technical reports or environmental documents | Mailing technical studies or environmental reports to other agencies and leaders of organized groups or interests. | Provides full and detailed information to people who are most interested. Often increases credibility of studies because they are fully visible. | Costs money to print and mail. Some people may not even read the reports. |
| News conferences | Brief presentation to reporters, followed by question-and-answer period, often accompanied by handouts of presenter's comments. | Stimulate media interest in a story. Direct quotes often appear in television/radio. Might draw attention to an announcement or generate interest in public meetings. | Reporters will only come if the announcement/presentation is newsworthy. Cannot control how the story is presented, although some direct quotes are likely. |

TABLE 7 (CONTINUED)

PUBLIC INFORMATION TECHNIQUES

(73:43-44)

| Technique | Features | Advantages | Disadvantages |
|---|---|---|---|
| Newsletters | Brief description of what is going on in the siting study, usually issued at key intervals for all people who have shown an interest in the study. | Provide more information than can be presented through the media to those people who are most interested. Often used to provide information prior to public meetings or key decision points. Also maintain visibility during extended technical studies. | Require staff time and cost money to prepare, print, and mail. Stories must be objective and credible or people will react to newsletters as if they were propaganda. |
| Newspaper inserts | Much like a newsletter, but distributed as an insert in a newspaper. | Reach the entire community with *important information* such as project need and alternative sites being considered. Is one of the few mechanisms for reaching everyone in the community through which you can tell the story your way. | Requires staff time to prepare insert, and distribution costs money. Must be prepared to newspaper's layout specifications. Potential negative reaction to use of public funds for this purpose exists. |
| News releases | A short announcement or news story issued to the media to get interest in media coverage of the story. | May stimulate interest from the media. Useful for announcing meetings or major decisions or as background material for future media stories. | May be ignored or not read. Cannot control how the information is used. |
| Paid advertisements | Advertising space purchased in newspapers or on radio or television. | Effective for announcing meetings or key decisions. Story presented the way you want. | Advertising space can be costly. Radio and television may entail expensive production costs to prepare the ad. Potential negative reaction to use of public funds for this purpose exists. |

**TABLE 7 (CONTINUED)**

PUBLIC INFORMATION TECHNIQUES

(73:44)

| Technique | Features | Advantages | Disadvantages |
|---|---|---|---|
| Presentations to civic and technical groups | Deliver presentations, enhanced with slides or viewgraphs, to key community groups. | Stimulates communication with key community groups. Can also provide in-depth feedback. | Few disadvantages except some groups may be hostile. |
| Press kits | A packet of information distributed to reporters. | Stimulates media interest in the story. Provides background information which reporters use for future stories. | Has few disadvantages, except may be ignored. Cannot control how the information is used. |
| Public service announcements | Short announcement provided free of charge by radio and television stations as part of their public service obligations. | Useful for making announcements such as for public meetings. | Many organizations compete for the same space. Story may not be aired or may be aired at hours when there are few listeners. |

TABLE 8

PARTICIPATION TECHNIQUES

(73:50)

| Technique | Features | Advantages | Disadvantages |
|---|---|---|---|
| Advisory groups/task forces | A group of representatives of key interested parties is established. May be a policy, technical, or citizen advisory group. | Provide oversight to the siting process. Promote communication between key constituencies. Anticipate public reaction to publications or decisions. Provide a forum for reaching consensus. | Potential for controversy exists if "advisory" recommendations are not followed. Requires substantial commitment of staff time to provide support to committees. |
| Focus groups | Small discussion groups established to give "typical" reactions of the public. Conducted by professional facilitator. Several sessions may be conducted with different groups. | Provide in-depth reaction to publications, ideas, or decisions. Good for predicting emotional reactions. | Get reactions, but no knowledge of how many people share those reactions. Might be perceived as an effort to manipulate the public. |
| Hotline | Widely advertised phone number to handle questions or provide centralized source of information about the siting. | Gives people a sense that they know whom to call. Provides a one-step service of information. Can handle two-way communication. | Is only as effective as the person answering the hotline phone. |
| Hearings | Formal meetings where people present formal speeches and presentations. | May be used as a "wrap-up meeting" prior to final decision. Useful in preparing a formal public record for legal purposes. | Exaggerates differences. Does not permit dialogue. Requires time to organize and conduct. |
| Interviews | Face-to-face interviews with key officials, interest group leaders, or key individuals. | Can be used to anticipate issues or anticipate the reactions of groups to a decision. Can also be used to assess "how are we doing." | Requires extensive staff time. |

**TABLE 8 (CONTINUED)**

PARTICIPATION TECHNIQUES

(73:50-51)

| Technique | Features | Advantages | Disadvantages |
|---|---|---|---|
| Meetings | Less formal meetings for people to present positions, ask questions, and so forth. | Highly legitimate form for the public to be heard on issues. May be structured to permit small group interaction—anyone can speak. | Unless small-group discussion format is used, permits only limited dialogue. May get exaggerated positions or grandstanding. Requires staff time to prepare for meeting. |
| Workshops | Smaller meetings designed to complete a task. | Very useful for tasks such as identifying siting criteria or evaluating sites. Permits maximum use of dialogue, good for consensus-building. | Limitations on size may require several workshops in different locations. Is inappropriate for large audiences. Requires staff time for multiple meetings. |
| Plebiscite | Citywide election to decide where or whether a facility should be built. | Provides a definite, and usually binding, decision on where or whether a facility should be built. | "Campaign" is expensive and time-consuming. General public may be susceptible to uninformed emotional arguments. |
| Polls | Carefully designed questions are asked of a portion of the public selected as representative of public opinion. | Provides a quantitative estimate of general public opinion. | Provides a "snapshot" of public opinion at a point in time—opinion may change. Assumes all viewpoints count equally in decision. Costs money and must be professionally designed. |

## III. Methodology

### Overview

Currently, there are models available to evaluate the economic feasibility of HRIs. Both the Army's Heat Recovery Incinerator Feasibility Model and the Navy's Civil Engineering Laboratory Heat Recovery Incinerator Model determine economic costs and benefits of HRIs (55:10; 49:31). However, they fail to consider other factors critical to the decision making process.

The decision model proposed in this paper will incorporate environmental, economic, and sociopolitical factors. Each factor will constitute a separate gate within the model, as shown in Figure 5. Gate one will evaluate environmental compliance with respect to air emissions. It will identify the current regulatory air pollution emission levels for HRIs under 250 TPD and identify air pollution control devices to satisfy these requirements. Gate two will involve development of an economic evaluation methodology for the HRI alternatives. Gate three will assess the local sociopolitical climate. It will involve the development of a survey questionnaire that allows the user to evaluate the sociopolitical acceptability of the proposed HRI, and estimate the resource requirements to process the alternative in accordance with NEPA. For the model to operate effectively, it must identify acceptable alternatives and eliminate unacceptable ones.

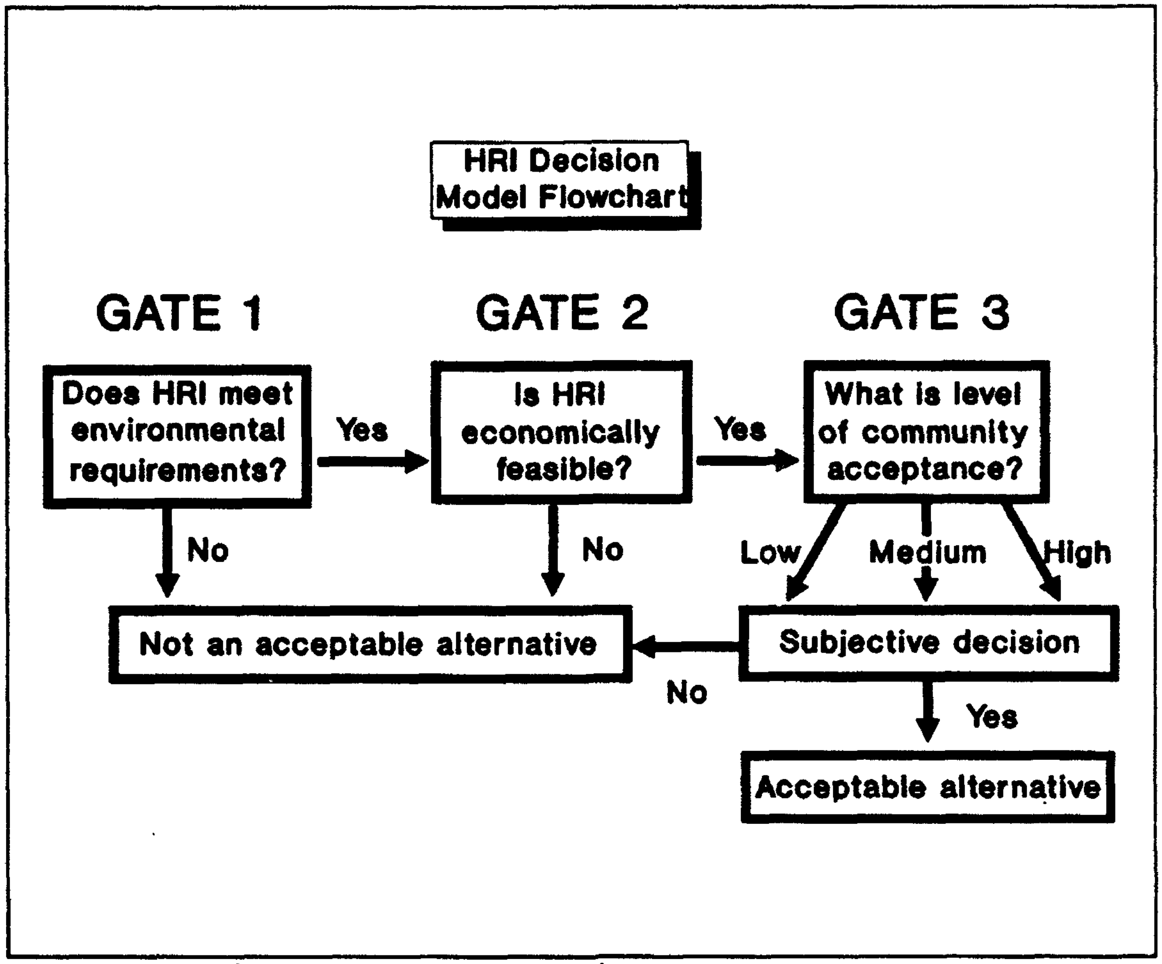


**Figure 5.** HRI Decision Model Flowchart

<u>Decision Model Development Methodology</u>

This section outlines the procedure proposed to develop each gate. It includes a description of the intended purpose of each gate as well as each gate's specific information requirements, data collection requirements, and methods of data analysis for gate development.

<u>Gate One</u>. As identified in the literature review, air pollution control is a significant factor in modeling the actual construction and operating costs of a HRI. The model

proposed in this research will assume that HRI costs are more a function of air pollution control requirements than wastewater control requirements. Consequently, the model will treat air pollution control as the critical factor in order to develop cost equations in gate two. Wastewater control will not be considered as a separate factor in developing HRI cost equations, but will be accounted for in the coefficients of the annual and capital cost equations. Therefore, gate one will only focus on environmental compliance of HRIs with respect to the air. This gate will investigate the HRI air pollution control configurations that will comply with the latest environmental laws and regulations for air emissions. The process will compare federal regulatory pollutant limits with emissions from incinerators having various air pollution control devices. Those air pollution control configurations capable of achieving emissions levels within federal limits will be identified for use in gate two of the model.

Gate one will require the identification of federal regulatory pollutant levels for MSW incinerator air emissions. These levels are identified in the latest NSPS for small MSW combustors (less than or equal to 250 TPD capacity), which are available from the USEPA. The next step will involve gathering pollution emissions data for various HRI air pollution control configurations. Incinerator manufacturers (see Table 9), as well as the USEPA, may provide data concerning specific emissions for existing HRIs. Com-

**TABLE 9**

INCINERATOR MANUFACTURERS

(58)

| | |
|---|---|
| Advanced Combustion<br>2183 East Bakerview<br>Bellingham, WA 98226<br>(Mr. Mike Milne) | EnerWaste Intl. Corp.<br>212 McKenzie Ave.<br>Bellingham, WA 98225<br>(Mr. Tom Dutcher) |
| ATCO Services North<br>212 McKenzie Ave.<br>Bellingham, WA 98225<br>(Mr. Frank Zurilne) | Joy Energy Systems, Inc.<br>11900 Westhall Dr.<br>Charlotte, NC 29217<br>(Mr. Steve Shuler) |
| Basic Engineering, Inc.<br>21 W. 161 Hill Street<br>Glen Ellyn, IL 60137<br>(Mr. John Cieslak) | Research Technology Corp.<br>200 Milton St.<br>Dedham, MA 02026<br>(Mr. Brian Hogan) |
| Bio-Energy, Ltd.<br>P.O. Box 10628<br>Fort Smith, AR 72917<br>(Mr. Robert G. Gillson) | Resource Technology Corp.<br>2931 Soldiers Springs Rd.<br>Laramie, WY 82070<br>(Mr. Robert Rucinski) |
| Brule C.E. & E., Inc.<br>13920 S. Western Ave.<br>P.O. Box 35<br>Blue Island, IL 60406<br>(Mr. Jim Moore) | Simonds Manufact Corp.<br>304 Progress Rd.<br>P.O. Box 1404<br>Auburndale, FL 33823<br>(Mr. Michael McDonald) |
| Chem-Solv, Inc.<br>13037 Winding Trail Lane<br>St. Louis, MO 63131<br>(Mr. Paul Bakula) | Synergy Systems Corp.<br>P.O. Box 27-3252<br>Boca Raton, FL 33427<br>(Mr. William McMillen) |
| Consumat Systems, Inc.<br>P.O. Box 9379<br>Richmond, VA 23227<br>(Mr. Matte Anderson) | Total Waste Mgt Service<br>4227 Earth City Express-<br>way, St. Louis, MO 63045<br>(Mr. Mark Bragovich) |

paring this data with federal limits for various types of pollutants (particulates, acid gases, nitrogen oxides, dioxins/furans, and carbon monoxide) will identify configurations capable of achieving required emissions levels.

Gate Two. Gate two will evaluate HRIs economics with each of the air pollution control configurations satisfying gate one. This will involve an analysis of the proposed alternatives using a computer life-cycle costing program.

To perform the analysis, the following data will be required for each alternative: 1) capital costs, 2) annual operations and maintenance (O&M) costs, 3) annual energy costs, and 4) annual refuse disposal costs. Capital costs and O&M costs for HRIs are available from existing facilities (reference Appendix D). Regression analyses of these capital and O&M costs will be used to develop equations that estimate these costs for generic HRI systems. Energy and refuse disposal costs will be site-specific. A life-cycle cost analysis incorporating these costs will be developed to determine the economic feasibility of the alternatives.

<u>Gate Three</u>. This gate will help to assess the sociopolitical acceptability of the HRI and may help evaluate the level of effort required to accomplish the NEPA process for the HRI. Gate three is proposed for use by base officials in making subjective decisions whether or not to commit the level of resources required to pursue the HRI proposal.

The survey will propose questions focusing on attitudes of people in the community, the local government, and environmental groups towards HRIs. The sum of the survey response values will determine an overall score. A comparison of this score to the range of possible scores will rate community acceptance as high, medium, or low. A low acceptance rating may indicate the need for a higher level of Air Force resources to accomplish the NEPA process for the HRI.

To determine the sociopolitical climate for community acceptance of a proposed HRI, a Likert-scale survey will be developed. Information to develop the questions that will gauge the sociopolitical acceptability of HRIs will be required. This information will be obtained through consultation with Wright-Patterson AFB environmental management/public affairs personnel and from a review of USEPA guidance on the siting of solid waste treatment and disposal facilities. Screening the information provided by these sources will provide the basis for development of specifc questions to be included in the survey. Following the development of the questions, evaluation by Air Force environmental management, civil engineering, and public affairs personnel from various installations will provide feedback to modify and validate the survey.

## Summary

This chapter outlines the methodology for developing the HRI decision model. It identifies how the three gates to evaluate HRI feasibility will be developed. Gate one will evaluate environmental compliance of proposed HRI alternatives. Gate two will involve the development of an economic analysis methodology for the proposed HRI alternatives. Gate three will assess the local sociopolitical climate and estimate the level of effort required to accomplish the NEPA process for the proposed HRI.

# IV. Decision Model Development

## Overview

This chapter outlines the development and the use of the modular HRI decision model for Air Force installations. The model consists of three gates. The first gate presents the current New Source Performance Standards (NSPS) for air emissions from MSW combustors. These standards determine the selection of acceptable air pollution control devices, determined in the literature review to have a significant effect on the actual construction and operating costs of a HRI. This gate then identifies the air pollution control devices necessary to ensure compliance with these requirements. Gate two presents an economic analysis methodology for each HRI alternative using the life-cycle cost (LCC) technique. A hypothetical scenario is provided to promote an understanding of the analysis process. The last gate proposes a survey that is intended to evaluate the sociopolitical acceptability of the HRI alternative. Based on the survey results, this gate should estimate the level of effort required to process the proposed HRI in accordance with the National Environmental Policy Act (NEPA).

## Gate One

As identified in the literature review, air pollution control is a significant factor in modeling the actual construction and operating costs of a HRI. This model assumes that HRI costs are more a function of air pollution control requirements than wastewater control requirements. Consequently, this model treats air pollution control as the critical factor for the development of cost comparisons in gate two. Therefore, gate one focuses on environmental compliance of HRIs with respect to the air. It reviews the current regulatory air pollution emission levels for HRIs under 250 TPD and identifies air pollution control processes/devices that will satisfy these requirements. As identified in chapter one, Air Force installations do not generate enough MSW for incinerator units greater than 250 TPD.

Current Air Emission Requirements. Table 10 lists the federal regulatory requirements (NSPS) for incinerator air pollutants. Note that although there are $NO_x$ limits for

**TABLE 10**

EMISSIONS STANDARDS FOR HRIS (≤250 TPD)

(6:1325)

| | |
|---|---|
| Metal Emissions | |
| Particulate Matter (mg/dscm) | 34 |
| Opacity (%) | 10 |
| Organic Emissions | |
| Total Dioxins and Furans (ng/dscm) | 75 |
| Acid Gas Emissions<br>% reduction or (emissions - ppmv) | |
| Hydrogen Chloride (HCl) | 80<br>(25) |
| Sulfur Dioxide ($SO_2$) | 50<br>(30) |
| Nitrogen Oxides ($NO_x$) | None |

incinerators greater than 250 TPD (reference Table 5), no regulations currently exist for plants less than or equal to 250 TPD. Also, Table 10 does not list emission limits for carbon monoxide (these limits are listed in Table 4). Carbon monoxide emissions are controlled through good combustion practices (reference Table 6), not a specific air pollution control device. Users of this decision model also need to identify any applicable state and local regulatory air emissions requirements for HRI operations. The most stringent regulatory requirements will govern the operation of the facility and the selection of pollution control devices.

If the location of the proposed HRI is within a nonattainment area (reference Appendix B), the addition of the new incinerator must be coupled with a pollution reduction that more than offsets this new increase in emissions within the region. Pollution reduction can be accomplished by reducing emissions from existing base facilities (internal offsets), using emission offsets obtained in the past (banked offsets), reducing emissions from other sources in the nonattainment area (external offsets), or purchasing the rights to pollute from an existing source within the nonattainment area (43:104). If construction of a HRI will require any of these actions, the additional costs must be identified as a capital cost in gate two of this model.

<u>Identification of Air Pollution Control Processes</u>. To identify pollution control devices and processes that can

meet the federal regulatory requirements in Table 10, manufacturers listed in Table 9 were surveyed (see Appendix C) to provide emission information for their equipment. However, the survey response was inadequate to provide useful data for analysis. Manufacturers did not monitor the air emissions performance of their incineration equipment after installation. Therefore, useful data was unavailable. Another reason cited by manufacturers' representatives was that emissions from MSW HRIs are largely determined by the chemical composition of the refuse. Furthermore, several manufacturers focused on a specialized incineration market, such as medical waste. Since medical waste has characteristics that differ from MSW, emissions and regulatory requirements vary.

Therefore, to identify acceptable air pollution control devices and processes for HRIs, gate one development incorporates data from three studies.

The first study, Technological and Economic Evaluation of Municipal Solid Waste Incineration, was sponsored by the University of Illinois Center for Solid Waste Management and Research (51). It contains "estimates of emissions without the use of air pollution control technology" (51:21). This information helps to establish an estimated baseline of air emissions from uncontrolled HRIs.

The USEPA sponsored the second study, Municipal Waste Combustors-Background Information for Proposed Standards: 111(b) Model Plant Description and Cost Report (69). This study develops anticipated air emission levels for 50, 100, and 240 TPD model modular WTE plants using various air pollution control configurations.

The third study, Municipal Waste Combustors-Background Information for Proposed Standards: Post-Combustion Technology Performance, is another USEPA sponsored investigation. It "...evaluates the performance of various air pollution control devices applied to new and existing municipal waste combustors" (68:1-1). Instead of modeling anticipated emissions from facilities, this study evaluates actual emissions from existing facilities.

Study One. The University of Illinois study evaluates existing excess-air and starved-air modular incinerators to generate generic estimates of emissions from modular HRIs without air pollution control equipment. The estimates are generic because of the variance in the refuse composition burned at the various plants. Comparing the emissions data identified in study one with the federal regulatory requirements reveals the need for air pollution control on modular HRIs (see Table 11).

Study Two. The second study models anticipated emissions for new 50 TPD (without heat recovery) and 100 TPD (with heat recovery) starved-air modular plants, and a new 240 TPD (with heat recovery) excess-air modular plant, using three different air pollution control processes. The first process uses good combustion practices (reference Table 6), an electrostatic precipitator for particulate control, and no acid gas control. The second process uses good combustion practices, a fabric filter or electrostatic precipitator for particulate control, and dry sorbent injection for acid gas control. The third process incorporates good combustion practices, a fabric filter for particulate control, and a spray dryer for acid gas control (69:2-5). All anticipated emissions are reported on a 7% $O_2$, dry basis, which is one of the accepted standards used by the USEPA to report incinerator emissions.

Since incinerator emissions are a function of waste composition, the model assumes each plant would use a consistent type of MSW. Table 12 identifies the composition of the hypothetical waste that the model plants would use.

**TABLE 11**

AVERAGE EMISSION CONCENTRATIONS FOR UNCONTROLLED MODULAR MUNICIPAL SOLID WASTE COMBUSTORS VS. FEDERAL LIMITS (51:22)

| Pollutant | Average | Limit |
|---|---|---|
| Particulate Matter (mg/dscm) | 272.00 | 34 |
| Sulfur Dioxide (ppmv) | 76.55 | 30 |
| Nitrogen Dioxide (ppmv) | 271.86 | None |
| Carbon Monoxide (ppmv) | 40.35 | 50 |
| Hydrogen Chloride (ppmv) | 586.44 | 25 |
| Cadmium (mg/dscm) | 0.63 | None |
| Lead (mg/dscm) | 13.50 | None |
| Mercury (mg/dscm) | 0.47 | None |
| Total CDD & CDF (ng/dscm) | 226.18 | 75 |

**TABLE 12**

REFUSE COMPOSITION

(69:1-5)

| Constituent | Percentage |
|---|---|
| Carbon | 26.7 |
| Hydrogen | 3.6 |
| Oxygen | 19.7 |
| Sulfur | 0.1 |
| Nitrogen | 0.2 |
| Water | 27.1 |
| Chlorine | 0.3 |
| Inerts | 22.2 |

Tables 13, 14, and 15 list USEPA estimates of air pollution emissions from the 50, 100, and 240 TPD model modular incinerators. Since waste composition is assumed the same for each plant, the similarity in emission level concentrations between the 50 and 100 TPD plants (Tables 13 and 14) show that facility size and heat recovery capability do not affect air emission concentrations. Although total air pollution emissions change with incinerator size, concentrations should remain relatively constant.

Furthermore, emission concentrations for the excess-air plant (Table 15) and the starved-air plants (Tables 13 and 14) are the same except for dioxins/furans and carbon monoxide. This implies that although particulate matter and acid gas formation are not a function of the type of modular incinerator, dioxin/furan and carbon monoxide levels are a function of the incineration process. Higher combustion temperatures in both chambers of an excess-air incinerator are one explanation for the lower concentrations of dioxins/furans compared with the starved-air design.

Comparing the results of the models with the federal regulatory requirements (Table 10) shows that processes one,

TABLE 13

EMISSIONS FOR 50 TPD STARVED-AIR MODULAR PLANT WITH VARIOUS AIR POLLUTION CONTROL PROCESSES

(69:7-39)

| Pollutant | Baseline | Process 1 | Process 2 | Process 3 |
|---|---|---|---|---|
| CDD/CDF | | | | |
| ng/dscm | 300 | 300 | 75 | 5 |
| Mg/yr | 1.2E-5 | 1.2E-5 | 3.0E-6 | 2.0E-7 |
| % reduction | - | 0 | 75 | 98 |
| CO | | | | |
| ppmv | 50 | 50 | 50 | 50 |
| Mg/yr | 3 | 3 | 3 | 3 |
| % reduction | - | 0 | 0 | 0 |
| Particulates | | | | |
| mg/dscm | 227 | 23 | 23 | 23 |
| Mg/yr | 9 | 1 | 1 | 1 |
| % reduction | - | 88 | 88 | 88 |
| $SO_2$ | | | | |
| ppmv | 200 | 200 | 120 | 20 |
| Mg/yr | 23 | 23 | 14 | 2 |
| % reduction | - | 0 | 40 | 90 |
| HCl | | | | |
| ppmv | 500 | 500 | 100 | 15 |
| Mg/yr | 31 | 31 | 6 | 1 |
| % reduction | - | 0 | 80 | 97 |

two, and three will sufficiently control particulate emissions. Processes two and three will lower dioxin/furan and hydrogen chloride emissions within required limits. However, of the three control configurations modeled, only process three will reduce sulfur dioxide to acceptable levels. Therefore, study two identifies two pollution control devices (one for particulates, one for acid gases) necessary to adequately control emissions from a modular HRI. It identifies that the only acceptable air pollution control alter-

**TABLE 14**

EMISSIONS FOR 100 TPD STARVED-AIR MODULAR PLANT WITH VARIOUS AIR POLLUTION CONTROL PROCESSES (69:7-40)

| Pollutant | Baseline | Process 1 | Process 2 | Process 3 |
|---|---|---|---|---|
| CDD/CDF | | | | |
| ng/dscm | 300 | 300 | 75 | 5 |
| Mg/yr | 3.9E-5 | 3.9E-5 | 9.7E-6 | 6.5E-7 |
| % reduction | - | 0 | 75 | 98 |
| CO | | | | |
| ppmv | 50 | 50 | 50 | 50 |
| Mg/yr | 8 | 8 | 8 | 8 |
| % reduction | - | 0 | 0 | 0 |
| Particulates | | | | |
| mg/dscm | 181 | 23 | 23 | 23 |
| Mg/yr | 24 | 3 | 3 | 3 |
| % reduction | - | 88 | 88 | 88 |
| $SO_2$ | | | | |
| ppmv | 200 | 200 | 120 | 20 |
| Mg/yr | 72 | 72 | 44 | 7 |
| % reduction | - | 0 | 40 | 90 |
| HCl | | | | |
| ppmv | 500 | 500 | 100 | 15 |
| Mg/yr | 100 | 100 | 20 | 3 |
| % reduction | - | 0 | 80 | 97 |

native of the three processes is a fabric filter and spray dryer absorber, coupled with good combustion practices.

Study Three. The third study evaluates the performance of various air pollution control devices. It records actual emissions from a variety of MSW incinerators operating with different air pollution control configurations. Specifically, it evaluates the following air pollution control processes:

**TABLE 15**

EMISSIONS FOR 240 TPD EXCESS-AIR MODULAR PLANT WITH VARIOUS AIR POLLUTION CONTROL PROCESSES

(69:7-32)

| Pollutant | Baseline | Process 1 | Process 2 | Process 3 |
|---|---|---|---|---|
| CDD/CDF | | | | |
| ng/dscm | 200 | 200 | 50 | 5 |
| Mg/yr | 6.2E-5 | 6.2E-5 | 1.6E-5 | 1.6E-6 |
| % reduction | - | 0 | 75 | 98 |
| CO | | | | |
| ppmv | 100 | 100 | 100 | 100 |
| Mg/yr | 40 | 40 | 40 | 40 |
| % reduction | - | 0 | 0 | 0 |
| Particulates | | | | |
| mg/dscm | 181 | 23 | 23 | 23 |
| Mg/yr | 57 | 7 | 7 | 7 |
| % reduction | - | 88 | 88 | 88 |
| $SO_2$ | | | | |
| ppmv | 200 | 200 | 120 | 20 |
| Mg/yr | 174 | 174 | 105 | 17 |
| % reduction | - | 0 | 40 | 90 |
| HCl | | | | |
| ppmv | 500 | 500 | 100 | 15 |
| Mg/yr | 239 | 239 | 48 | 7 |
| % reduction | - | 0 | 80 | 97 |

1) an electrostatic precipitator (ESP) with no acid gas control,

2) a fabric filter (FF) or ESP with dry sorbent injection (DSI), and

3) a fabric filter or electrostatic precipitator with a spray dryer absorber (SDA).

Emissions data for these three processes is contained in Tables 16-20. All emission concentrations are measured at 7% $O_2$, dry basis. Although the data includes information

**TABLE 16**

MSW INCINERATOR PARTICULATE (PM) AND CDD/CDF
CONTROL USING AN ESP
(PM - MG/DSCM, CDD/CDF - NG/DSCM)
(68:2-60 to 2-84)

| Location | PM Inlet | PM Outlet | CDD/CDF Inlet | CDD/CDF Outlet |
|---|---|---|---|---|
| Barron Co., WI[a] | - | 24.3 | - | - |
| Oneida Co., NY[a] | - | 63.1 | - | 462 |
| Oswego Co., NY[a] | | | | |
| Test 1 (inlet to ESP 494°F)[c] | 785 | 57.2 | 175 | 353 |
| Test 2 (inlet to ESP 483°F)[c] | 428 | 36.6 | 195 | 301 |
| Test 3 (inlet to ESP 491°F)[c] | 485 | 27.5 | 359 | 412 |
| Test 4 (inlet to ESP 467°F)[c] | 787 | 64.1 | 732 | 819 |
| Pigeon Point, DE[b] | | | | |
| Unit 1 | 2498 | 7.0 | - | - |
| Unit 2 (inlet to ESP 412°F)[c] | 2522 | 3.6 | - | 105 |
| Unit 3 | 2178 | 4.6 | - | - |
| Unit 4 | 1048 | 12.9 | - | - |
| Alexandria, MN[a] | | | | |
| Unit 1 | - | 60.6 | - | - |
| Unit 2 (inlet to ESP 496°F)[c] | - | 89.7 | - | 446 |

[a] Designed for old PM emission standard of 69 mg/dscm

[b] Designed for new PM emission standard of 34 mg/dscm

[c] Inlet temperature is only for the CDD/CDF test

TABLE 17

MSW INCINERATOR ACID GAS CONTROL USING A FF OR AN ESP WITH DSI (CONCENTRATIONS IN PPMV) (6:1327; 68:4-3)

| Location | HCl In | HCl Out | % Red | $SO_2$ In | $SO_2$ Out | % Red |
|---|---|---|---|---|---|---|
| Claremont, NH | | | | | | |
| Unit 1 (FF) | 788 | 104 | 87 | - | 231 | - |
| Unit 2 (FF) | 642 | 37 | 94 | - | 60 | - |
| Springfield, MA (FF) | 533 | 33 | 94 | 137 | 23 | 83 |
| St. Croix, WI (FF) | 743 | ≈0 | 100 | 99 | 28 | 72 |
| Dayton, OH (ESP) | | | | | | |
| Test 1 | 187 | 34 | 81 | 114 | 55 | 52 |
| Test 2 | 181 | 23 | 88 | 129 | 35 | 73 |
| Test 3 | 200 | 40 | 78 | 121 | 59 | 50 |
| Test 4 | 126 | 17 | 86 | 111 | 36 | 68 |
| Test 5 | 111 | 9 | 92 | 119 | 39 | 67 |
| Test 6 | 94 | 12 | 87 | 72 | 42 | 42 |
| Dutchess Co., NY | | | | | | |
| Unit 1 (FF) | - | 30 | - | 121 | 105 | 16 |
| Unit 2 (FF) | - | 183 | - | 138 | 123 | 10 |

from facilities over 250 TPD, this model assumes emissions concentrations will be independent of facility size.

Table 16 summarizes particulate matter and dioxin/furan (CDD/CDF) emission levels for various incinerators operating with only ESPs. Table 17 shows acid gas levels and Table 18 shows particulate and CDD/CDF levels for various facilities using a DSI with a FF or a DSI with an ESP. Table 19 pres-

**TABLE 18**

MSW INCINERATOR PM AND CDD/CDF CONTROL
USING A FF OR AN ESP WITH DSI
(PM - MG/DSCM, CDD/CDF - NG/DSCM)
(6:1328; 68:4-9,11)

| Location | PM Conc In | PM Conc Out | CDD/CDF Conc Out |
|---|---|---|---|
| Claremont, NH | | | |
| Unit 1 (FF), 5/87 | - | 26.7 | - |
| 7/87 | - | - | 37.6 |
| Unit 2 (FF), 5/87 | - | 10.4 | - |
| 7/87 | - | - | 32.3 |
| Springfield, MA (FF) 7/88 * Reported as 2,3,7,8 tetrachlorinated dibenzodioxin equivalent (EPA method) | 218.3 | 3.9 | 0.16 * |
| St. Croix, WI (FF) | | | |
| 5/88 | - | 36.4 | - |
| 6/88 | - | 36.4 | - |
| 10/88 | - | 29.1 | - |
| Dayton, OH (ESP) Test 5 (inlet to ESP 306°F)[a] | 1358 | 7.8 | 57.2 |
| Dutchess Co., NY | | | |
| Unit 1 (FF), 2/89 | - | 23.5 | 4.8 |
| Unit 2 (FF), 2/89 | - | 84.9 | 17.9 |
| 3/89 | - | 26.7 | - |
| 5/89 | - | 19.2 | - |

[a] Inlet temperature is only for the CDD/CDF test

ents acid gas levels and Table 20 shows particulate and CDD/CDF emissions for incinerators that use a SDA/FF or a SDA/ESP.

The results identified in Table 16 reveal that ESPs are very effective for controlling particulate matter. However,

TABLE 19

MSW INCINERATOR ACID GAS CONTROL USING A FF OR ESP WITH A SDA (CONCENTRATIONS IN PPMV) (6:1328)

| Location | HCl In | HCl Out | % Red | $SO_2$ In | $SO_2$ Out | % Red |
|---|---|---|---|---|---|---|
| Marion County, Oregon Unit 1, 6/87 (FF) | 646 | 48 | 93 | 333 | 151 | 55 |
| Biddeford, ME Unit A, 12/87 (FF) | 582 | 5.8 | 99 | 101 | 23 | 78 |
| Mid-Connecticut Unit 11, 7/88 | 478 | 4.5 | 99 | - | - | - |
| 1/89 (FF) | 389 | 16 | 96 | 175 | 12 | 93 |
| SEMASS Unit 1, 3/89 (ESP) | - | - | - | 154 | 67 | 57 |
| Unit 2, 4/89 (ESP) | - | - | - | 162 | 55 | 65 |
| Millbury, MA Unit 1, 2/88 (ESP) | 770 | 23 | 97 | 205 | 54 | 74 |
| Unit 2, 2/88 (ESP) | 697 | 6.1 | 99 | 296 | 62 | 79 |

the data also reflect that ESPs appear to promote CDD/CDF formation.

> [Municipal Waste Combustion] facilities equipped with only an ESP for PM control exhibit higher CDD/CDF concentrations at the outlet than at the inlet for ESP operating temperatures higher than approximately 230°C (450°F), an indicator that PM control devices can operate as reactors which generate CDD/CDF. (6:1325)

**TABLE 20**

MSW INCINERATOR PM AND CDD/CDF CONTROL
USING A FF OR ESP WITH A SDA
(PM-MG/DSCM, CDD/CDF-NG/DSCM)

(6:1329)

| Location | PM In | PM Out | % Δ | CDD CDF In | CDD CDF Out | % Δ |
|---|---|---|---|---|---|---|
| Marion County, OR Unit 1, 9/86 (SDA/FF) | 2137 | 5.6 | 99 | 43 | 1.3 | 96 |
| Biddeford, ME Unit A, 12/87 (SDA/FF) | 7761 | 34 | 99 | 903 | 4.4 | 99 |
| Mid-Connecticut Unit 11, 7/88 | 5845 | 9.7 | 99 | 1056 | 0.7 | 99 |
| 2/89 (SDA/FF) | 4317 | 4.4 | 99 | 792 | 0.4 | 99 |
| Millbury, MA Unit 1, 2/88 (SDA/ESP) | - | 4.4 | - | - | - | - |
| Unit 2, 2/88 (SDA/ESP) | - | 20 | - | 170 | 59 | 65 |
| SEMASS Unit 1, 3/89 (SDA/ESP) | 10380 | 19 | 99 | - | 9.3 | - |
| Unit 2, 4/89 (SDA/ESP) | 9362 | 29 | 99 | - | 311 | - |

Although ESPs control particulates, users of this model must consider their propensity for generating CDDs and CDFs at high inlet operating temperatures. Applying the good combustion practices outlined in Table 6 can help to minimize this problem. Also, users must realize that ESPs alone do not offer any reduction in acid gas emissions.

The data show that to control acid gas, particulate, and CDD/CDF emissions, a combination of air pollution control technologies is necessary. One combination is DSI with either a FF or an ESP.

Although it appears that a DSI system (with an ESP or FF) is capable of controlling acid gas emissions within federal regulatory percentage reduction limits, the data reflect a difficulty in achieving regulatory concentration levels (reference Table 17).

With respect to particulate control, the DSI/ESP configuration at the Dayton facility met federal standards, and the facilities with DSI/FF arrangements met standards in 8 out of 10 cases (reference Table 18).

For CDD/CDF control, both the DSI/ESP and DSI/FF configurations met federal emissions standards in all cases (reference Table 18). The data indicate that CDD/CDF removal is assisted by a DSI and FF or ESP combination. This may be explained by the temperature drop of the flue gas as it passes through the DSI, before moving through the particulate control device (6:1326). "Reduced flue gas temperatures...are believed to promote adsorption of CDDs, CDFs, and other organics onto fine particles having relatively large surface areas" (6:1327), thus removing CDDs and CDFs with particulate removal.

A second technology combination that will control acid gases, particulates, and CDD/CDF emissions is a SDA with either a FF or an ESP.

The SDA system (with an ESP or FF) also appears to be capable of controlling acid gas emissions within federal regulatory percentage reduction limits. However, the data reflect a difficulty in achieving regulatory concentration levels for $SO_2$ emissions, while four of the five HCl concentration levels fall within standards (reference Table 19).

As for particulate control, all the SDA/ESP and SDA/FF configurations met federal standards (reference Table 20).

For CDD/CDF control, the SDA/FF configuration met federal regulatory concentration standards in all cases (reference Table 20). The SDA/ESP combination met regulatory concentration levels in two of the three cases. However, the SDA/FF arrangement appears to be more efficient at reducing CDD/CDF emissions than the SDA/ESP combination. Again, this might be explained by the potential for CDD/CDF generation in an ESP under certain circumstances.

Results of study three show that either the SDA/FF or SDA/ESP will comply with regulatory requirements for acid gases, particulates, and CDD/CDF emissions.

Gate One Summary. Information from the three studies in gate one identify the air pollution control configurations for a modular HRI that would be necessary to comply with NSPS requirements.

Study one identified mean emissions from uncontrolled starved-air and excess-air modular incinerators. The emissions data revealed the need for air pollution control on modular HRIs in order to meet federal regulatory levels.

Study two identified anticipated emissions from modular incinerator models using various pollution control processes. The study revealed that a modular incinerator with an ESP as its sole air pollution control device could not meet regulatory requirements. It also predicted that an incinerator with a DSI/FF (or DSI/ESP) would not reduce sulfur dioxide to acceptable levels. Therefore, this study identifies the SDA/FF system (coupled with good combustion practices) as an acceptable air pollution control alternative.

Study three supported the assertions formulated in study two. Testing on existing MSW incinerators showed that either the SDA/FF or SDA/ESP would comply with regulatory requirements for acid gases, particulates, and CDD/CDF emissions. The SDA/FF configuration appeared to be more reliable than the SDA/ESP at controlling CDD/CDF emissions. These results are substantiated by the USEPA's selection of a SDA/FF (with good combustion practices) as the technological basis for establishing federal air emission standards for municipal waste combustors (reference Table 6).

Therefore, a modular HRI configured with either a SDA/FF or a SDA/ESP are the two configurations to be included in the economic evaluation of alternatives outlined in gate two.

## Gate Two

The purpose of gate two is to develop an economic analysis methodology to determine the economic feasibility of the modular HRI alternatives. The development of gate two involves three steps.

The first step is to estimate the size of HRI that the installation can support based on the quantity of MSW generated. The user should be aware that in calculating the amount of refuse available for incineration, the USEPA recommends using a refuse density of 666 pounds per cubic yard. However, MSW densities vary from installation to installation. Therefore, the user should determine an average density of the MSW for their installation to calculate the HRI size requirement.

The second step is to identify the costs associated with the environmentally feasible modular HRI alternatives identified in gate one, as well as other alternatives. The alternatives require the identification of capital costs, salvage values, annual costs (e.g., operations and maintenance, fuel, refuse disposal, etc.), and non-annually recurring costs (e.g., permitting) prior to performing the economic analysis. Regression equations may be used to estimate the capital costs as well as annual operations and maintenance (O&M) costs for the modular HRI alternatives (in 1991 dollars). Eqs (6) and (7) model the capital costs for HRIs with a SDA/FF and a SDA/ESP, respectively. Eqs (8) and (9) model the annual O&M costs for HRIs with a SDA/FF and a SDA/ESP, respectively. Development of these regression equations is integrated into the modular HRI cost section of a hypothetical scenario that follows. However, the user can employ these equations to estimate capital and annual O&M costs for modular HRI alternatives (with a SDA/FF or a SDA/ESP) for their specific situation. The model also offers users the flexibility to input manufacturer-provided cost data. Table 9 lists some of the current HRI vendors.

The third step involves the economic evaluation of these alternatives using a LCC technique. Specifically, this model uses the National Institute of Standards and Technology Building Life Cycle Cost (BLCC) Computer Program (Version 3.1) (41) along with the Life-Cycle Costing Manual for the Federal Energy Management Program (53). The BLCC program incorporates energy escalation factors from the Energy Prices and Discount Factors for Life-Cycle Cost Analysis 1992 (32) report. Results of the LCC analysis will assist the user in deciding whether to continue to gate three of the model.

The following hypothetical scenario, developed from information pertaining to the Wright-Patterson AFB, Ohio, Area B heat plant (building 770) and base waste disposal contracts, should help the user understand the economic analysis process outlined above. An analysis of four alternatives, a "do-nothing" (leave existing system intact) and a boiler replacement alternative (replace coal-fired boiler with a natural gas-fired boiler), as well as the two modular HRI alternatives which passed gate one (incinerator with SDA/FF or with SDA/ESP pollution control devices), forms the basis for comparison to determine HRI economic feasibility.

In this scenario, the portion of the heat plant that is thermodynamically equivalent to the heat generated by incinerating all MSW generated at Wright-Patterson AFB determined the size of the boiler replacement and each modular HRI alternative.

Estimation of HRI Size. Wright-Patterson AFB determined their average MSW density to be 1000 pounds per cubic yard (37). Using this figure, the base generates approximately 115 TPD of MSW. Assuming a recycling rate of 10 percent, this study uses 100 TPD as the basis for determining cost data for each alternative.

Identification of Costs. The "do-nothing," boiler replacement, and modular HRI alternatives each require the identification of capital costs, salvage values, and annual costs to perform an economic analysis. The BLCC economic analysis requires all costs to be in constant dollars. For this scenario, all costs were converted to 1992 dollars. An assumed five percent inflation factor converted 1991 dollars to 1992 dollars.

"Do-Nothing" Costs. Capital costs associated with the "do-nothing" alternative are zero. The assumptions made in this example are that the salvage value for the "do-nothing" alternative is zero and the "do-nothing" alternative has the same study period as the other alternatives (26 years).

Annual costs for this alternative include the current MSW disposal contract costs as well as existing heat plant

O&M and fuel costs. The O&M and fuel costs are based on the thermodynamic equivalency mentioned previously.

The MSW disposal costs include both the housing and base contracts. This amounts to an annual cost of approximately \$810,000 (7; 27).

The O&M cost for the "do-nothing" alternative is the O&M cost for an existing boiler that could be replaced by a 100 TPD modular HRI (capable of providing an equivalent quantity of steam). The following equation computes the rated steam output for a 100 TPD modular HRI:

$$\frac{(100\mathrm{TPD})(2000\mathrm{lb/ton})(4500\mathrm{BTU/lb})}{(24\mathrm{hr/day})(1191\mathrm{BTU/lb})}(.9) = 28{,}338\mathrm{lb/hr} \qquad (3)$$

where

100 TPD = size of HRI in tons per day

4500 BTU/lb = heat content of MSW (18:3.141)

1191 BTU/lb = enthalpy of saturated steam at 125 psi (74:718)

.9 = assumed thermal efficiency of the HRI (based on actual performance of the HRI at Fort Lewis, Washington) (24:96-97)

The actual output of one of the existing small boilers at Wright-Patterson AFB (approximately 26,000 lb/hr) (36) is within the rated steam output capacity of the 100 TPD HRI (28,338 lb/hr). Therefore, the prorated O&M cost for the existing boiler (based on a ratio of the rated capacity of the existing boiler to the rated capacity of the entire plant) is the O&M cost for the "do-nothing" alternative.

The annual O&M cost for this particular boiler is approximately $135,000 (25).

The annual fuel cost for the "do-nothing" alternative is the cost of coal to fire the existing boiler. These costs equate to the energy input of a 100 TPD modular HRI burning 4500 BTU/lb MSW, as outlined in the following equation:

$$\frac{\mathbf{(100TPD)\,(2000lb/ton)\,(4500BTU/lb)\,(\$2.26/MBTU)\,(365day/yr)}}{\mathbf{(1{,}000{,}000BTU/MBTU)}}$$

$$= \mathbf{\$742{,}410\ per\ year} \qquad (4)$$

where

100 TPD = size of HRI in tons per day

4500 BTU/lb = heat content of MSW (18:3.141)

$2.26/MBTU = coal cost in 1992 dollars (52)

Therefore, the estimated annual fuel cost for the "do-nothing" alternative is approximately $750,000 (52).

<u>Boiler</u> <u>Replacement</u> <u>Costs</u>. For the hypothetical scenario, the capital cost for the boiler replacement alternative is the capital cost for a natural gas boiler that equates in rated steam output to a 100 TPD modular HRI (28,338 lb/hr of steam). Modifying a capital cost estimate of $3.2 million for a 160,000 lb/hr natural gas plant (using Chilton's "six-tenths factor" for estimating costs based on economies of scale), the capital cost for this alternative is about $1.2 million [(28,338 lb/hr ÷ 160,000 lb/hr) raised

to the 0.6 power x ($3.2 million)] (9; 36). Based on this capital cost the salvage value equates to $120,000 (assuming the salvage value is 10 percent of the capital cost of the facility).

This capital cost does not include any permitting costs. The user may decide to include permitting costs (must include if permitting costs vary between alternatives) and treat them as non-annually recurring cost inputs to the BLCC program. This hypothetical scenario assumes permitting costs equal for each alternative and therefore does not include them.

Annual costs for this alternative include the current MSW disposal contract costs, natural gas heat plant O&M costs, and natural gas fuel costs.

The MSW disposal costs include both the housing and base contracts. As with the "do-nothing" alternative, this amounts to an annual cost of approximately $810,000 (7; 27).

For this example, operating costs for a coal-fired and a natural gas-fired boiler are assumed to be equal. Therefore, the annual O&M cost estimate for this alternative is $135,000 (25).

The annual fuel cost for the boiler replacement alternative is the cost of natural gas to fire a new boiler. These costs equate to the energy input of a 100 TPD modular HRI burning 4500 BTU/lb MSW, as outlined in the following equation:

$$\frac{(100TPD)(2000lb/ton)(4500BTU/lb)(\$4.00/MBTU)(365day/yr)}{(1{,}000{,}000BTU/MBTU)}$$

$$= \$1{,}314{,}000 \text{ per year} \tag{5}$$

where

100 TPD = size of HRI in tons per day

4500 BTU/lb = heat content of MSW (18:3.141)

$4.00/MBTU = natural gas cost in 1992 dollars (52)

Consequently, the estimated annual fuel cost for this alternative is $1,314,000 (52).

Modular HRI Costs. A multiple regression analysis (results in Appendix F) was performed to estimate capital costs for the modular HRI alternatives, based on the information in Appendix D. Appendix D contains pertinent information for all modular HRIs in operation (as of January 1990) in the United States. Data in Appendix D was inflated from 1987 to 1991 dollars using an inflation conversion factor of 1.1945 (inflation for 1988 through 1991 was 4.1%, 4.9%, 6.1%, and 3.1%, respectively) (20:64; 29). Based on the results of gate one, the analysis incorporated only those plants with dry scrubbers and baghouses (fabric filters).

The independent variables found most significant for this multiple regression analysis were steam output and facility size (X variables). The variable for the number of full time plant personnel was eliminated through stepwise examination. The dependent variable (Y variable) was capital cost.

Dividing the significant variables by the number of boilers/units adjusted the data to a unit basis (the model assumes the proposed HRI consists of one boiler/unit). Furthermore, area cost factors (ACFs) in Appendix E adjusted cost data to the Wright-Patterson AFB area (ACF equal 1.00). For example, the 120 TPD HRI at Fort Lewis, Washington, had two boilers/units, a steam output of 37,000 pounds per hour (lb/hr), and a total cost of $11.95 million (reference Appendix D). The adjusted data reflected a unit size of 60 TPD (120 TPD ÷ 2 units), a steam output of 18,500 lb/hr (37,000 lb/hr ÷ 2 units), and a capital cost of $5.98 million ($11.95 million ÷ 2 units ÷ Fort Lewis' ACF of 1.00).

The regression analysis for capital costs of a modular HRI with a SDA/FF yielded the following equation (reference Appendix F):

$$CC = 2.4991 + 0.0009(TPD) + 0.0002(STM) \qquad (6)$$

where

CC = capital cost for HRI with a SDA/FF, in millions of 1991 dollars (multiply this cost by the appropriate ACF in Appendix E to adjust to a specific location)

TPD = facility size in tons per day

STM = steam output in pounds per hour

The resulting correlation coefficient of 0.9560 and the mean absolute deviation (MAD) of 0.8633 show this regression equation is statistically representative of the existing population.

Inserting 100 TPD as the facility size and 26,000 lb/hr (36) as the steam output into Eq (6), and multiplying by an ACF of 1.00 for Wright-Patterson AFB (reference Appendix E), the estimated capital cost for a 100 TPD modular HRI with a SDA/FF is $8,179,000 (inflated from 1991 to 1992 dollars). Based on this capital cost the salvage value is $817,900 (assuming salvage value is 10 percent of capital cost).

As mentioned, Eq (6) only represents the capital cost of constructing a modular HRI with SDA/FF air pollution control. Since capital costs associated with an ESP are less than that of a FF, this equation must be modified. Based on information for a 100 TPD starved-air modular incinerator contained in the study Technological and Economic Evaluation of Municipal Solid Waste Incineration (51:82), the difference in capital costs between a HRI with a SDA/FF configuration and a SDA/ESP arrangement is approximately $5,921 per TPD (converted from 1986 to 1991 dollars). Assuming a linear relationship of $5,921 per TPD over the range of interest (HRI size ranging from 1 to 150 TPD), and subtracting 0.005921 from the TPD coefficient in Eq (6) (0.0009), the equation for capital costs of a modular HRI with SDA/ESP air pollution control is:

$$CC = 2.4991 - 0.005021(TPD) + 0.0002(STM) \qquad (7)$$

where

CC = capital cost for HRI with a SDA/ESP, in millions of 1991 dollars (multiply this cost by the appropriate ACF in Appendix E to adjust to a specific location)

TPD = facility size in tons per day

STM = steam output in pounds per hour

Using the same values in Eq (7) used to determine the SDA/FF capital cost, the estimated capital cost for a 100 TPD modular HRI with a SDA/ESP is $7,560,000 (inflated from 1991 to 1992 dollars). Based on this capital cost the salvage value is $756,000 (assuming salvage value is 10 percent of the capital cost).

These regression equations for capital costs do not include nonattainment area offset or permitting costs. Nonattainment area offset costs (if applicable) must be added to the capital cost. The user may decide to include permitting costs (must include if permitting costs vary between alternatives) and treat them as non-annually recurring cost inputs to the BLCC program. This hypothetical scenario assumes nonattainment area offset costs are zero. It also assumes permitting costs are equal for each alternative and therefore does not include them.

Annual costs for both modular HRI alternatives include HRI O&M costs and the cost of collecting and transporting refuse to the incineration site (boiler fuel costs are zero).

A multiple regression analysis was also performed to develop an estimator of annual O&M costs for the HRI alternatives. Again, the information in Appendix D applies, and the results of the regression analysis are shown in Appendix G. The analysis incorporates only those plants with dry scrubbers and baghouses (fabric filters).

The independent variables found most significant for this multiple regression analysis were steam output, number of employees, and facility size (X variables). The dependent variable (Y variable) was annual cost.

Of the six facilities involved in the regression analysis to determine annual O&M costs, three identified ash tip fees (the cost to dispose of the ash byproduct). For those HRIs with a specified ash tip fee, the annual O&M cost was increased to reflect this additional cost prior to performing the regression. For example, the Windham facility pays an ash tip fee of $8.75 per ton, has an ash to refuse ratio of 0.39, and operates at a capacity of 108 TPD (reference Appendix D). Therefore, the annual O&M cost increased by $134,521 (108 TPD x 0.39 x $8.75/ton x 365 days/year). Facilities without a listed ash tip fee are assumed to include this cost as part of their annual O&M cost.

Again, the data was adjusted to a unit basis by dividing each variable by the number of boilers/units, and by adjusting costs using both ACFs and an inflation factor. Subsequently, the regression analysis for annual costs of a modular HRI with a SDA/FF yielded the following equation (reference Appendix G):

$$AC = 0.1479 - 0.0126(TPD) + 0.0000739(STM) + 0.1110(PN) \quad (8)$$

where

AC = annual cost for HRI with a SDA/FF, in millions of 1991 dollars (multiply this cost by the appropriate ACF in Appendix E to adjust to a specific location)

TPD = facility size in tons per day

STM = steam output in pounds per hour

PN = number of full-time employees

The resulting correlation coefficient of 0.9981 and the MAD of 0.0264 show this regression equation is statistically representative of the existing population.

Inserting 100 TPD as the facility size, 26,000 lb/hr (36) as the steam output, and 5 people (prorated number of personnel required to operate existing boiler) (2) into Eq (8), and multiplying by an ACF of 1.00 for Wright-Patterson AFB (reference Appendix E), the estimated annual O&M cost for a 100 TPD modular HRI with a SDA/FF is approximately $1,433,000 (inflated from 1991 to 1992 dollars).

This equation only represents the annual cost of operating and maintaining a modular HRI with SDA/FF air pollution control. Since annual costs associated with an ESP are less than that of a FF (primarily due to periodic FF replacement costs), this equation must also be modified. Based on information for a 100 TPD starved-air modular incinerator contained in the study _Technological and Economic Evaluation of Municipal Solid Waste Incineration_ (51:82), the difference in annual O&M costs between a HRI with a SDA/FF configuration and a SDA/ESP arrangement is approximately $1,321 per TPD (converted from 1986 to 1991 dollars). Assuming a linear relationship of $1,321 per TPD over the range of interest (HRI size ranging from 1 to 150 TPD), and subtracting 0.001321 from the TPD coefficient in Eq (8) (-0.0126), the equation for annual O&M costs of a modular HRI with SDA/ESP air pollution control is:

$$AC = .1479 - .013921(TPD) + .0000739(STM) + .1110(PN) \tag{9}$$

where

AC = annual cost for HRI with a SDA/ESP, in millions of 1991 dollars (multiply this cost by the appropriate ACF in Appendix E to adjust to a specific location)

TPD = facility size in tons per day

STM = steam output in pounds per hour

PN = number of full-time employees

Using the same values in Eq (9) used to determine the SDA/FF annual O&M cost, the estimated annual O&M cost for a 100 TPD modular HRI with a SDA/ESP is $1,293,000 (inflated from 1991 to 1992 dollars).

Besides the normal annual O&M costs associated with operating a HRI (e.g., maintenance costs, repair costs, employee salaries, etc.), there is an additional cost to collect and transport refuse to the incinerator. The existing MSW disposal contracts at Wright-Patterson AFB include the cost to collect the refuse, transport it to off-base sites, and tipping fees to dispose of it. Since Wright-Patterson AFB pays the refuse contractor a lump sum, the determination of this expense involved subtracting tipping fees and transportation costs. For this scenario, the estimated annual cost to collect and transport the waste to an on-base modular HRI is $427,000 (27).

Summary of Costs. Table 21 summarizes the costs of the hypothetical scenario identified in the previous sections. Note that the annually recurring O&M costs identified in Appendices H and I are the sum of the annual MSW disposal and annual O&M costs listed in Table 21.

Life-Cycle Cost Analysis. The BLCC computer program evaluates alternatives for economic feasibility. The Life Cycle Costing Manual for the Federal Energy Management Program identifies a discount rate of seven percent for energy conservation projects and a maximum life of 25 years for new and retrofitted facilities (53:29,41). For this hypothetical scenario, a discount rate of seven percent and a study period of 26 years (a 1-year construction period plus a 25-year life) was used for each alternative, except for the "do-nothing" case. The "do-nothing" alternative had a 26-year study period and a 0-year construction period.

Appendix H is a report of data inputs to the BLCC program for each alternative. Appendix I summarizes the cash flows identified for each alternative. Finally, Appendix J lists the LCC for each alternative.

## TABLE 21

SUMMARY OF COSTS FOR THE HYPOTHETICAL SCENARIO

| Cost | "Do-Nothing" ($000) | Boiler Replace ($000) | HRI w/ SDA/FF ($000) | HRI w/ SDA/ESP ($000) |
|---|---|---|---|---|
| Capital | 0 | 1,200[d] | 8,179 | 7,560 |
| Salvage | 0 | 120 | 817.9 | 756 |
| Annual MSW Disposal | 810[a] | 810[a] | 427[e] | 427[e] |
| Annual O&M | 135[b] | 135[b] | 1,433 | 1,293 |
| Annual Fuel | 750[c] | 1,314[c] | 0 | 0 |

[a] (7; 27)
[b] (25)
[c] (52)
[d] (36)
[e] (27)

The results of this life-cycle cost analysis are identified in Table 22. Assuming the "do-nothing" alternative is not an option, they show that constructing modular HRIs would be more economical on a LCC basis than the natural gas boiler replacement alternative.

Gate Two Summary. This gate provides the user a means to economically evaluate modular HRIs. The regression equations developed in this gate for modular HRI capital costs and annual O&M costs are summarized in Appendix K. The economics of the modular HRIs become more attractive when it is necessary to replace existing boilers (when doing nothing is not acceptable). Eliminating the "do-nothing" alternative leaves the following three options to consider:

**TABLE 22**

LIFE-CYCLE COST ANALYSIS RESULTS

| Alternative | Initial Cost | Life-Cycle Cost |
|---|---|---|
| "Do-Nothing" | $ 0 | $21,241,940 |
| HRI with SDA/ESP | $7,560,000 | $26,162,690 |
| HRI with SDA/FF | $8,179,000 | $28,295,800 |
| Nat Gas Boiler | $1,200,000 | $29,743,540 |

1) replace the existing boiler (to burn coal, fuel oil, or natural gas), 2) replace the existing system with a modular HRI and SDA/FF combination, or 3) replace the existing system with a modular HRI and SDA/ESP arrangement. The hypothetical scenario only considered the replacement of a coal-fired boiler with a natural-gas fired boiler for the boiler replacement alternative. Furthermore, high fuel and MSW disposal costs will also improve the economic feasibility of the HRIs. Based on the user's cost inputs, gate two will determine whether or not the HRI alternatives should proceed to gate three.

Gate Three

The purpose of gate three is to present a survey that is intended to evaluate the sociopolitical acceptability of the proposed HRI, and estimate the resource requirements to process the alternative in accordance with NEPA. The survey is an internal tool for use by base environmental management or civil engineering personnel. Users should avoid direct contact with the public when completing the survey. Any contact with the public must be made by public affairs personnel to avoid creating unnecessary alarm.

The information to develop this survey was intended to be obtained through consultation with Wright-Patterson AFB environmental management/public affairs personnel as well as from a review of USEPA guidance on the siting of solid waste treatment and disposal facilities. However, following consultation with base personnel, it was apparent that there was a lack of expertise regarding the sociopolitical impacts concerning HRI construction and operation. This may be explained by a lack of experience in siting such a facility. Consequently, the information to develop specific questions for the survey was obtained strictly through a review of USEPA literature.

The survey is a Likert-scale questionnaire (reference Appendix L) assessing health risk, siting/operating, multi-media pollution, and waste reduction issues, identified from a review of current literature to be the major sociopolitical areas of concern. The following four sections identify the questions in the survey, what the possible responses to the questions indicate, and where the user can obtain information to accurately answer them. The final sections of gate three interpret the results of the sociopolitical survey and summarize gate three of the model.

<u>Health Risk Questions</u>. The first question in the survey asks, "What level of impact on their health do you

feel the public will perceive from the operation of a modular HRI?" Possible responses are low, medium, or high. A low response indicates the public believes the risk to their health from a modular HRI would be minimal.

Knowledge of past public reaction to projects with potential environmental impacts (e.g., medical waste incinerators; hazardous waste treatment, storage, or disposal facilities; industrial facilities; landfills; etc.) can help indicate the degree to which the public may feel the HRI is a health risk. This information may be available from sources such as public affairs, the base historian, the library (local newspaper articles and periodical literature), and local community planning meeting minutes.

The second question asks, "How will the operation of a modular HRI effect human health compared to current heat plant operations?" This question addresses the actual health risks associated with the operation of a modular HRI. It focuses on comparing the quantitative risk associated with a HRI with the risk from current heat plant operations. The question prompts the user to identify whether the risk will be reduced, unchanged, or increased. The user should identify a reduction in risk if emissions from the HRI represent an improvement over current operations.

Emissions information for existing heat plant operations (from air permit) as well as emission requirements for modular HRIs (from latest New Source Performance Standards) can help indicate whether the health risk will increase or decrease. The user can obtain assistance in assessing the risk by contacting the USEPA Office of Air Quality and Standards Pollutant Assessment Branch at (919) 541-5344.

Siting/Operation Questions. The first question in this section of the survey asks, "What effect will the modular HRI have on property values in the local community?" Possible responses are that the facility will have little effect, moderate effect, or major effect on property values.

The user should have an awareness of the negative effect that other waste-to-energy facilities have had on property values to respond to this question. This information may be found through local planning agencies in areas having similar facilities. State and regional EPA points of contact (reference Appendix M) can provide locations of waste-to-energy facilities throughout the United States. The user should use this information, coupled with the proximity of the nearest residential area to the proposed site, to make a subjective response to this question.

The next question asks, "What will be the visual impact of the HRI facility on the surrounding community?" It addresses the visual impact of the HRI facility (the structure itself, not the emissions from the facility). The question asks the user to identify whether the HRI has no impact, a moderate impact, or a major impact on the visual aesthetics of the surrounding community. If the facility is not visible from off-base, the user should provide a response of no impact.

The proposed siting for the HRI will help the user determine what the visual impacts will be. The base community planner can provide potential sites for constructing the HRI.

The third question in this section of the survey asks, "What is the relationship between the Air Force and the local community?" In response to the question the user characterizes this relationship as good, fair, or poor. A poor response indicates a higher potential for community opposition to a proposed HRI.

To answer this question the user should have an awareness of the past and current association between the base and local community. This information should be available from discussions with public affairs, the base historian, the base civil engineer, and the base commander.

The last question in this section of the survey asks, "What degree of influence do environmental groups have in the local area?" It addresses the influence of environmental groups (e.g., Sierra Club, Greenpeace, Audobon Society, Environmental Defense Fund, etc.) in the community. Replies of minimal, moderate, or extreme influence are possible. If a group is very active and highly visible the user would respond that these groups have a high level of influence in the community. This would indicate a greater potential for organized opposition to the siting of a HRI.

To respond to this question the user should be familiar with the activities of environmental groups in the local area. Records of demonstrations or litigations involving these groups may provide insight into their potential for resistance. Public affairs, the base historian, the base legal office, and local newspapers are sources for this information.

Multimedia Pollution Questions. Given that the proposed HRI will comply with air emissions regulatory requirements, the first question under this section of the survey asks, "What will be the aesthetic impact of HRI emissions on air quality compared to current heat plant operations?" The user may respond that the HRI will have a positive impact, no impact, or a negative impact on aesthetic air quality compared to continued operation of the existing facility. An example of a positive impact could be less visible smoke from a HRI versus the emissions from an existing coal-fired heat plant. A negative impact could be the amount of visible smoke from a proposed HRI compared with the emissions from an existing natural gas-fired heat plant.

To answer this question the user needs to compare aesthetic factors such as smoke (opacity) and odor, for both the existing heat plant and the proposed HRI. The user can obtain opacity information for existing operations from heat plant logs, permit requirements, and the facility's compliance record. For the proposed modular HRI, the New Source Performance Standards identify required opacity levels. Furthermore, opacity readings from existing modular HRIs with appropriate air pollution control equipment (identified in gate one of this model) will indicate the expected visual quality of emissions from new HRIs. Locations of modular HRIs in the United States are available from state and regional EPA points of contact (reference Appendix M). Users can also visit these facilities to identify potential odor problems from HRI operations, and incorporate this information into their response.

Given that both the proposed HRI and the existing heat plant comply with water quality regulatory requirements, the next question asks, "What will be the aesthetic impact of HRI emissions on water quality compared to current heat plant operations?" Potential responses are that the HRI will have a positive impact, no impact, or a negative impact on water quality compared to continued operation of the existing facility. An example of a positive impact could be less total suspended solids in rainwater runoff from a HRI site (MSW storage area) compared with the runoff from the site of an existing coal-fired heat plant (coal storage area). A negative impact could be runoff from the area surrounding the HRI (which carries associated debris into a receiving stream) compared with runoff from an existing natural gas-fired heat plant.

To respond to this question the user needs to rely on subjective judgement in assessing how the existing heat plant and the proposed HRI may effect the aesthetic quality of a receiving body of water. Again, the user can visit existing HRIs to gather information to respond to this question. The user should also be aware of the type of fuel used by the existing heat plant (coal, fuel oil, or natural gas) and how it is handled, prior to making the decision. This can help indicate whether the existing heat plant will have more potential problems with runoff (e.g., total suspended solids, visible oil sheen, odors, etc.) than a HRI (stray refuse).

Waste Reduction Question. The waste reduction question asks, "How does the base waste reduction/recycling program compare with local community programs?" The user may respond that the base program is better, the same, or worse than local community programs. A better base program may indicate that there would be less public opposition to the HRI since steps are being taken to reduce and recycle the refuse prior to incineration. If the base program is worse, then officials may need to focus efforts on recycling and source reduction before they consider incineration as an alternative.

The user needs to identify the documented efforts of both the base and the community's programs in order to answer this question. Environmental management or civil engineering personnel should have base information. City, county, or state solid waste management departments may have local community recycling and reduction information.

Sociopolitical Survey Interpretation and Validation. This survey helps indicate the sociopolitical acceptance of the proposal as well as estimate the level of base resources (e.g., staff, money, time, etc.) required to complete the NEPA process. Predicting the reaction of individual citizens, interest groups, and local agencies to a HRI proposal (sociopolitical acceptability) can identify the degree of opposition to the proposed HRI, and subsequently indicate the level of Air Force resources necessary for the NEPA process. For instance, low sociopolitical acceptance may indicate the potential for increased resistance in issuing a FONSI (for an EA) on the proposed HRI. Low sociopolitical acceptance may also signify greater opposition in the scoping process (for an EIS). Both would result in increasing the expenditure of Air Force time, money, and manpower required to fulfill NEPA requirements.

Possible survey scores range from a low of 9 to a high of 27. A score of 9 indicates a high potential for acceptance of the proposed HRI in the local community. This also indicates the potential for a lower expenditure of base resources during the NEPA process in order to proceed with the proposed HRI. Conversely, a score of 27 shows a high potential for opposition to HRI construction. It also indicates the potential for a larger resource requirement to accomplish the NEPA process and proceed with the proposed HRI.

This survey is a subjective tool for determining the sociopolitical acceptability of a proposed HRI. In this regard, it does not ensure the acceptance or rejection of the proposal. The closer the score is to an extreme, the greater the degree of certainty concerning sociopolitical acceptance or rejection, and the more accurate the estimate of Air Force resources required for the NEPA process. However, scores that fall between the two extremes ("grey area") indicate a higher level of uncertainty as to the acceptability of the HRI alternative. For scores that fall towards the middle of this "grey area," the decision-maker should make a final subjective call as to the feasibility of the alternative.

The original proposal was to validate this survey using Air Force environmental management, civil engineering, and public affairs personnel. However, due to a lack of expertise in the Air Force regarding the issues of HRI construction and operation, validation as originally planned was not possible. An appropriate population for the purpose of validating this survey would include city planners and city managers with experience at siting these facilities. However, once an appropriate population was identified, time constraints prohibited the validation phase of the research proposal.

Gate Three Summary. This gate provides the user a method of evaluating the sociopolitical acceptability of a new HRI and it may indicate the resources required to guide the alternative through the NEPA process. The literature shows that four major areas of concern are health risk, siting and operations, multimedia pollution, and waste reduction issues. Gate three consists of a Likert-scale survey containing questions from each of these areas. These questions are intended to measure the sociopolitical climate of the local community regarding a proposed HRI. The survey score can help the decision-maker determine whether or not the construction of a HRI will be an acceptable alternative. As previously mentioned, this survey, although based on USEPA guidelines and information, still requires validation.

## Summary of Decision Model Development

This chapter traced the development and application of the modular HRI decision model for Air Force installations. The model incorporated three gates.

The first gate identified current federal air emission requirements for HRI pollutants and revealed the required air pollution control options to ensure compliance. The two options were a spray dryer absorber with a fabric filter (SDA/FF) and a spray dryer absorber with an electrostatic precipitator (SDA/ESP).

Gate two developed a methodology for an economic analysis of the HRI alternatives identified in gate one using life-cycle costing techniques. It also provided a hypothetical scenario to promote an understanding of the analysis process.

The last gate introduced a survey intended to evaluate the sociopolitical acceptability of the proposed HRI and to determine the level of resources required to process the alternative in accordance with NEPA. This survey, although based on USEPA guidelines and information, was not validated. An appropriate population for the purpose of validating this survey could include city planners, city managers, and other individuals with experience at siting MSW incineration facilities.

# V. Conclusions and Recommendations for Further Research

## Conclusions

This research revealed that the construction of modular heat recovery incinerators on Air Force installations may be feasible. Air Force decision makers must consider environmental, economic, and sociopolitical factors in making this determination at specific locations. The decision model presented in this research will help determine the feasibility of constructing HRIs on Air Force bases.

From an environmental perspective, this research revealed that the applicable laws and regulations include the National Environmental Policy Act (NEPA), the Resource Conservation and Recovery Act (RCRA), the Clean Air Act (CAA), and the Clean Water Act (CWA).

Currently, the most significant federal rules impacting HRIs are the New Source Performance Standards (NSPS) under the CAA. The latest NSPS regulate air pollution emission levels for particulates, acid gases, dioxins/furans, and carbon monoxide. These emissions must be controlled by appropriate air pollution control devices in combination with good combustion practices. The research showed that currently the best air pollution control equipment options for handling these emissions are a spray dryer absorber (SDA) with a fabric filter (FF), or a SDA with an electrostatic precipitator (ESP).

The CAA Amendments of 1990 require five year reviews/updates of the NSPS. Future updates may establish emission levels that cannot be achieved using existing air pollution equipment. They may also specify technologies that do not exist today as the basis for achieving these emission levels. Based on the latest NSPS, the user should identify which modular HRI air pollution control configurations are acceptable for implementation.

In addition to the CAA and the NSPS, the user of this model must take into consideration possible changes to NEPA, RCRA, and the CWA. For example, changing the categorization of MSW ash under RCRA (from non-hazardous to hazardous) would have extreme ramifications concerning the decision to construct a HRI.

Economically, the research identified the applicable costs associated with the modular HRI alternatives that were found to be environmentally feasible based on the requirements of the latest NSPS (a HRI with a SDA/FF or SDA/ESP air pollution control arrangement). Capital costs, annual costs (O&M, fuel, and MSW disposal costs), non-annually recurring costs (permitting and nonattainment area offset costs), and the salvage value associated with each alternative were the relevant costs/benefits necessary to perform an economic analysis. The research presented regression equations to estimate capital and annual O&M costs for modular HRIs. It also revealed that the required tool for performing an economic analysis to compare new HRI alternatives is the life-cycle cost technique.

Based on a hypothetical scenario at Wright-Patterson AFB, the research showed that replacing an existing coal-fired boiler with a modular HRI would be economically favorable to installing a natural gas-fired unit. Since a large number of the existing central heat plants in the Air Force are fuel oil-fired, and fuel oil is currently more costly than natural gas, replacing fuel oil-fired units with modular HRIs will probably also be economically feasible at Air Force installations. However, replacing coal-fired boilers with a HRI instead of a new coal-fired unit may not prove to be economically practical due to the relatively low cost of coal.

From a sociopolitical standpoint, the research identified that the major concerns with respect to HRI construction were health risk, siting/operation, multimedia pollution, and waste reduction issues. The research proposed a Likert-scale questionnaire reflecting these issues, designed to measure sociopolitical acceptability of modular HRIs on Air Force bases. The survey is an internal tool for use by base environmental management or civil engineering personnel.

While modular HRIs may be economically favorable compared to other alternatives, sociopolitically the reverse may be true. For example, although natural gas might prove less economically viable than a HRI alternative, the emissions from natural gas would be cleaner. Therefore, a natural gas-fired boiler might prove to be more sociopolitically acceptable than burning MSW, especially if the base's existing heat system uses natural gas. Conversely, if the existing infrastructure burns coal, HRI emissions may reduce overall health risk and prove more sociopolitically acceptable than replacing an old coal-fired unit with a new coal-fired unit.

The dynamics of the environmental, economic, and sociopolitical arenas support the assertion that all of these factors must be considered simultaneously when determining the feasibility of constructing HRIs on Air Force installations.

## Recommendations for Further Research

This study uncovered two potential areas for further research.

The first is a requirement for validation of the sociopolitical survey developed for use in gate three of the model. Since this questionnaire was developed through a literature review, a research technique such as the Delphi technique could help to provide feedback from experts (city planners and city managers with experience in siting MSW incinerators), thereby enhancing the effectiveness of the survey.

Second, the fiscal realities in the Department of Defense are that Air Force bases probably will not receive funds to construct HRIs unless they are to replace aging heat plants. A follow-on study employing this model at Air Force installations with central heat plants near the end of their useful lives will identify opportunities to use modular HRIs.

## Appendix A: Classification of RDF

(18:3.140)

| Class | Form | Description |
|---|---|---|
| 1 | Raw MSW | Municipal solid waste as a fuel in an as-discarded form without oversized bulky waste. |
| 2 | Coarse RDF | MSW processed to coarse particle size with or without ferrous-metal boiler separation, such that 95% by weight passes through a 6-in square mesh screen. |
| 3 | Prepared RDF | MSW processed to produce particle size such that 99% by weight passes through a 6-in square mesh screen. Ferrous recovery of at least 90% of the incoming MSW is specified, as is removal of the glass, grit, sand, and dirt fractions. |
| 4 | Recovery prepared RDF | The same as class 3 with the following additions:<br>- Processing to remove aluminum<br>- Processing to remove other non-ferrous metals<br>- Processing to prepare recovered ferrous, non-ferrous, and glass fractions for the resale market<br>- Processing to return the fine-fraction combustibles to the RDF fraction |
| 5 | Fluff RDF | Shredded fuel derived from MSW processed for the removal of metal, glass, and other entrained inorganics; particle size of this material is such that 95% by weight passes through a 2-in square mesh screen. |
| 6 | Densified RDF | Combustible waste fraction densified (compressed) into pellets, slugs, cubettes, briquettes, or similar forms. Fluff RDF free of glass and grit is used as feed to densifying equipment. |

## Appendix B: Major Air Force Installations in National Ambient Air Quality Standards Nonattainment Areas

(67; 70:4-204)

| State, Base | Areas Included | Pollutant |
|---|---|---|
| **Alaska** | | |
| Elmendorf AFB Area | Part of Anchorage Election District | Carbon Monoxide |
| Eielson AFB Area | Part of Fairbanks Election District | Carbon Monoxide |
| **Arizona** | | |
| Luke AFB Area | Part of Maricopa County | Carbon Monoxide |
| | Part of Maricopa County | Ozone |
| | Part of Maricopa County | PM-10 |
| | Part of Maricopa County | TSP |
| Williams AFB Area | Part of Maricopa County | Carbon Monoxide |
| | Part of Maricopa County | Ozone |
| | Part of Maricopa County | PM-10 |
| Davis Monthan AFB Area | Part of Pima County | Carbon Monoxide |
| | Part of Pima County | PM-10 |
| | Part of Pima County | TSP |
| **California** | | |
| Edwards AFB Area | Part of Kern County | Carbon Monoxide |
| | All of Kern County | Ozone |
| | Part of Kern County | PM-10 |
| Los Angeles AFB Area | Part of Los Angeles Co. | Carbon Monoxide |
| | Part of Los Angeles Co. | Ozone |
| | Part of Los Angeles Co. | PM-10 |
| | Part of Los Angeles Co. | TSP |
| | Part of Los Angeles Co. | Nitrogen Dioxide |
| March AFB Area | Part of Riverside County | Carbon Monoxide |
| | Part of Riverside County | Ozone |
| | Part of Riverside County | PM-10 |
| | Part of Riverside County | TSP |
| | Part of Riverside County | Nitrogen Dioxide |
| Norton AFB Area | Part of San Bernardino Co. | Carbon Monoxide |
| | Part of San Bernardino Co. | Ozone |
| | Part of San Bernardino Co. | PM-10 |
| | Part of San Bernardino Co. | TSP |
| | Part of San Bernardino Co. | Nitrogen Dioxide |
| George AFB Area | Part of San Bernardino Co. | Carbon Monoxide |
| | Part of San Bernardino Co. | Ozone |
| | Part of San Bernardino Co. | PM-10 |
| | Part of San Bernardino Co. | TSP |
| McClellan AFB Area | Part of Sacramento County | Carbon Monoxide |
| | Part of Sacramento County | Ozone |
| | All of Sacramento County | TSP |
| Mather AFB Area | Part of Sacramento County | Carbon Monoxide |
| | Part of Sacramento County | Ozone |
| | All of Sacramento County | TSP |
| Onizuka AFB Area | Part of Santa Clara Co. | Carbon Monoxide |
| | All of Santa Clara County | Ozone |
| | All of Santa Clara County | TSP |
| Travis AFB Area | Part of Solano County | Carbon Monoxide |
| | Part of Solano County | Ozone |
| Castle AFB Area | All of Merced County | Ozone |
| Vandenberg AFB Area | All of Santa Barbara Co. | Ozone |
| | Part of Santa Barbara Co. | TSP |
| Beale AFB Area | All of Yuba County | Ozone |

## Appendix B: Major Air Force Installations in National Ambient Air Quality Standards Nonattainment Areas (Continued)

(67; 70:4-204)

| State, Base | Areas Included | Pollutant |
|---|---|---|
| Colorado | | |
| Air Force Academy Area | Part of El Paso County | Carbon Monoxide |
| Peterson AFB Area | Part of El Paso County | Carbon Monoxide |
| Falcon AFB Area | Part of El Paso County | Carbon Monoxide |
| Cheyenne Mt AFB Area | Part of El Paso County | Carbon Monoxide |
| Lowry AFB Area | Part of Arapahoe County | Carbon Monoxide |
| | Part of Arapahoe County | Ozone |
| | Part of Arapahoe County | PM-10 |
| | Denver Urban Area | TSP |
| Buckley AGB Area | Part of Arapahoe County | Carbon Monoxide |
| | Part of Arapahoe County | Ozone |
| | Part of Arapahoe County | PM-10 |
| Delaware | | |
| Dover AFB Area | All of Kent County | Ozone |
| District of Columbia | | |
| Bolling AFB Area | Entire Washington Area | Carbon Monoxide |
| | Entire Washington Area | Ozone |
| Florida | | |
| Homestead AFB Area | All of Dade County | Ozone |
| McDill AFB Area | All of Hillsborough Co. | Ozone |
| Georgia | | |
| Dobbins AFB (AFRES) Area | All of Cobb County | Ozone |
| Guam | | |
| Andersen AFB Area | Parts of Guam | Sulfur Dioxide |
| Illinois | | |
| Scott AFB Area | All of St. Clair County | Ozone |
| | Part of St. Clair County | TSP |
| Maine | | |
| Loring AFB Area | Part of Aroostook County | PM-10 |
| Maryland | | |
| Andrews AFB Area | Part of Prince George's Co. | Carbon Monoxide |
| | All of Prince George's Co. | Ozone |
| Massachusetts | | |
| Hanscom AFB Area | Part of Middlesex County | Carbon Monoxide |
| | All of Middlesex County | Ozone |
| | Part of Middlesex County | TSP |
| Westover AFB (AFRES) Area | Part of Hampden County | Carbon Monoxide |
| | All of Hampden County | Ozone |
| | Part of Hampden County | TSP |
| Otis AGB Area | All of Barnstable County | Ozone |
| Michigan | | |
| Selfridge AGB | Part of Macomb County | Carbon Monoxide |
| | All of Macomb County | Ozone |
| | Part of Macomb County | TSP |

## Appendix B: Major Air Force Installations in National Ambient Air Quality Standards Nonattainment Areas (Continued)

(67; 70:4-204)

| State, Base | Areas Included | Pollutant |
|---|---|---|
| Missouri | | |
| Richards-Gebaur AFB (AFRES) Area | All of Jackson County | Ozone |
| Montana | | |
| Malmstrom AFB Area | Part of Cascade County | Carbon Monoxide |
| | Part of Cascade County | TSP |
| Nevada | | |
| Nellis AFB Area | Part of Clark County | Carbon Monoxide |
| | Part of Clark County | PM-10 |
| | Part of Clark County | TSP |
| New Jersey | | |
| McGuire AFB Area | Part of Burlington County | Carbon Monoxide |
| | All of Burlington County | Ozone |
| New Mexico | | |
| Kirtland AFB Area | All of Bernalillo County | Carbon Monoxide |
| | Part of Bernalillo County | TSP |
| Ohio | | |
| Wright-Patterson AFB Area | All of Montgomery County | Ozone |
| | Part of Montgomery County | TSP |
| | All of Greene County | Ozone |
| Rickenbacker AGB Area | All of Franklin County | Ozone |
| Newark AFB Area | All of Licking County | Ozone |
| Texas | | |
| Carlswell AFB Area | All of Tarrant County | Ozone |
| South Dakota | | |
| Ellsworth AFB Area | Part of Meade County | TSP |
| Utah | | |
| Hill AFB Area | All of Davis County | Ozone |
| Virginia | | |
| Langley AFB Area | All of Hampton | Ozone |
| Washington | | |
| McChord AFB Area | Part of Pierce County | Carbon Monoxide |
| | All of Pierce County | Ozone |
| | Part of Pierce County | PM-10 |
| | Part of Pierce County | TSP |
| Fairchild AFB Area | Part of Spokane County | Carbon Monoxide |
| | Part of Spokane County | PM-10 |
| | Part of Spokane County | TSP |

## Appendix C: Survey Letter

**ENGINEERING AND ENVIRONMENTAL MANAGEMENT**
**AFIT/ENV**
**WRIGHT-PATTERSON AFB, OH 45433**

24 April 1992

Mr. Joe Smith
Incinerator Company
Smithville, OH 45431

Dear Mr. Smith

This fax is in reference to our recent telephone conversation concerning your line of modular incinerators. As previously stated, we are working on a Master's thesis for the Air Force. It involves building a model to help commanders determine the feasibility of installing heat recovery incinerators at Air Force installations.

Our model requires cost and pollution emissions data for various sizes/types of incinerators. A consolidation of inputs from various vendors will be used to generate typical emissions and cost data for our project. Our research document will include your company's name in a manufacturer's source list; however, your company's name will not be tied directly to your specific performance data. We appreciate your help in providing this information. We are interested in modular incinerators that burn raw municipal solid waste (4500 BTU/lb). The focus of our study is on units with capacities up to 100 tons per day.

The attachments are a sample of the information we are looking for, with pertinent instructions. They require inputs on emissions and cost data for your incinerators, with various pollution control equipment options. We would also appreciate a list of several customers with similar size/type systems.

In order to help answer any questions concerning this request, we will follow this fax with a telephone call within a week of receipt. Responses can be returned to our attention via fax (513-255-5188), or sent to the following address: Capt Art Anderson, 5848 Access Road, Dayton, OH 45431. Thank you very much for your time and support!

Sincerely

ARTHUR H. ANDERSON, JR.
Captain, USAF
Graduate Student

PAUL R. MUNNELL
Captain, USAF
Graduate Student

2 Atchs
1. Data Sheet
2. Instructions

MODULAR INCINERATOR DATA SHEET

Company Name ____________________ Model Name/Type ____________________

Size (TPD or BTU/hr) ________ Heat Recovery Ratio (lb[illegible]/lb[illegible]) ________

Pollution Control Equipment

| Emissions | None | Fabric Filter | Wet Scrubber |
|---|---|---|---|
| Lead (list units) | | | |
| Cadmium (list units) | | | |
| Mercury (list units) | | | |
| Particulates (mg/dscm) | | | |
| Opacity (%) | | | |
| CO (ppmv) | | | |
| $NO_x$ (ppmv) | | | |
| $SO_2$ (% or ppmv) | | | |
| HCl (% or ppmv) | | | |
| Dioxins (ng/dscm) | | | |
| Furans (ng/dscm) | | | |

Cost Data

| Costs | Incinerator | Incinerator w/Fabric Filter | Incinerator w/Wet Scrubber |
|---|---|---|---|
| Initial | | | |
| Operations & Maintenance | | | |

Atch 1.1

Appendix C: Survey Letter (Continued)

Pollution Control Equipment

| Emissions | Spray Dryer/ Dry Sorb Injec | Electrostatic Precipitator | Combination (specify) |
|---|---|---|---|
| Lead (list units) | | | |
| Cadmium (list units) | | | |
| Mercury (list units) | | | |
| Particulates (mg/dscm) | | | |
| Opacity (%) | | | |
| CO (ppmv) | | | |
| $NO_x$ (ppmv) | | | |
| $SO_2$ (% or ppmv) | | | |
| HCl (% or ppmv) | | | |
| Dioxins (ng/dscm) | | | |
| Furans (ng/dscm) | | | |

Cost Data

| Costs | Incinerator w/ Spray Dryer or Dry Sorb Injec | Incinerator w/ Electrostatic Precipitator | Incinerator w/ Combination (specify) |
|---|---|---|---|
| Initial | | | |
| Operations & Maintenance | | | |

Atch 1.2

INSTRUCTIONS

1. Enter company name, model, and size. Specify if size is in tons per day or BTU/hr (we are assuming raw municipal solid waste, with a heat value of 4500 BTU/lb). Use one form for each size of incinerator. We are looking at sizes of 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 tons per day. If your models do not match these specific sizes, list those with capacities of less than 100 tons per day.

EMISSIONS DATA

2. For each model, identify emission levels for each pollutant, with the various pollution control equipment specified. Data in the first column should reflect performance of the incinerator without pollution control (Atch 1.1). Use the last column to list pollution emissions for any combination of pollution control devices that may be standard with your modular incinerator designs (Atch 1.2). Please specify the combination. For example, a dry scrubber with baghouse. Please provide as much data as available for the various pollutants and pollution control devices. If you have information for lead, cadmium, and mercury, please specify the units of measure.

3. All emission levels are at 7 percent $O_2$, dry basis.

4. Dioxins/furans measured as total tetra- through octa-chlorinated dibenzo-p-dioxins and dibenzofurans, and not as toxic equivalents.

5. For $SO_2$ and HCl, list emissions as % reduction or ppmv.

6. Averaging times for emissions are as follows: 1) Opacity - 6 minutes, 2) CO - 4 hours, 3) $NO_x$ - 24 hours, and 4) $SO_2$ - 24 hours.

COST DATA

7. For each model also provide initial and annual O&M costs. Initial costs should include cost of equipment and installation. O&M costs should include general operations and maintenance expenses (labor, materials, etc.). Data in the first column should reflect costs for the incinerator without pollution control devices (Atch 1.1). Use the last column to list costs for any combination of pollution control devices that may be standard with your modular incinerator designs (Atch 1.2). Please specify the combination of equipment.

Atch 2

Appendix D: Heat Recovery Incinerators

(24:94-99)

| Location | Size (TPD) | APC[5] Equip | Steam Output (lb/hr) | Full Time People | Capital Cost[6] ($ M) | Annual Cost[6] ($ M) |
|---|---|---|---|---|---|---|
| Atlantic City, NJ | 15 | - | - | - | 1.79 | - |
| Sitka, AK | 24[1] | ESP | 5,200 | 5 | 5.42 | 0.30 |
| Center, TX | 40[1] | N | 7,000 | 7 | 2.23 | 0.43 |
| Carthage, TX | 40[1] | N | 10,000 | 7 | 1.98 | 0.54 |
| Newport News, VA | 40[2] | N | 8,200 | 5 | 2.64 | - |
| Mayport, FL | 50[1] | N | - | 10 | 3.81 | 0.59 |
| Burley, ID | 50[1] | N | 9,000 | 8 | 1.90 | 0.27 |
| Frenchville, ME | 50 | - | - | - | - | - |
| Collegeville, MN | 50[1] | WS | 10,000 | 11 | 3.73 | - |
| Hempfield Twp., PA | 50[2] | ESP | 10,000 | 8 | 4.85 | 0.84 |
| Waxahachie, TX | 50[1] | WS | 11,000 | 10 | 3.15 | 0.82 |
| Savage, MN | 57[1] | ESP | 13,500 | 4 | 4.59 | 0.82 |
| Lewisburg, TN | 60[1] | WS | 19,000 | 6 | 3.51 | 0.43 |
| Juneau, AK | 70[1] | - | - | - | - | - |
| Red Wing, MN | 72[1] | ESP | 15,000 | 10 | 4.97 | 1.25 |
| Franklin, KY | 75[2] | CYC | 15,000 | 9 | 3.95 | 1.21 |
| Ft Leonard Wood, MO | 75[3] | N | 8,740 | 12 | 4.73 | - |
| Livingston, MT | 75[1] | N | 13,000 | 6 | 3.92 | 0.78 |
| Fosston, MN | 80[3] | ESP | 25,000 | 13 | 8.00 | 1.82 |
| Alexandria, MN | 80[2] | ESP | 11,000 | 11 | 6.93 | 2.46 |
| Wrightstown, NJ | 80[4] | WS/B | 16,000 | 16 | 7.43 | 0.86 |
| Almena, WI | 80[2] | ESP | 16,500 | 14 | 7.00 | 1.61 |
| Fergus Falls, MN | 94[2] | WS | 30,000 | 13 | 4.78 | 1.79 |

[1,2,3,4] 1, 2, 3, or 4 boilers/units, respectively.
[5] APC Equipment: Baghouse (B), Dry Scrubber (DS), Cyclone (CYC), Electrostatic Precipitator (ESP), Wet Scrubber (WS), None (N).
[6] Costs are in 1991 dollars.

Appendix D: Heat Recovery Incinerators (Continued)

(24:94-99)

| Location | Ash/Refuse Ratio (TPD/TPD) | Ash Tip Fee ($/Ton) [1,2] |
|---|---|---|
| Atlantic City, NJ | - | - |
| Sitka, AK | 0.16 | N [3] |
| Center, TX | 0.33 | N |
| Carthage, TX | 0.34 | N |
| Newport News, VA | 0.11 | N |
| Mayport, FL | 0.39 | 12.54 |
| Burley, ID | 0.36 | N |
| Frenchville, ME | - | - |
| Collegeville, MN | 0.41 | 11.95 |
| Hempfield Twp., PA | 0.40 | 8.60/yd |
| Waxahachie, TX | 0.15 | N |
| Savage, MN | 0.33 | 20.90 |
| Lewisburg, TN | 0.27 | N |
| Juneau, AK | - | - |
| Red Wing, MN | 0.42 | N |
| Franklin, KY | 0.25 | 12.54/yd |
| Ft Leonard Wood, MO | 0.33 | N |
| Livingston, MT | 0.25 | N |
| Fosston, MN | 0.55 | 29.86 |
| Alexandria, MN | 0.25 | 31.06 |
| Wrightstown, NJ | 0.20 | 25.08 |
| Almena, WI | 0.40 | 17.92 |
| Fergus Falls, MN | 0.25 | N |

[1] Costs are in 1991 dollars.
[2] Ash tip fee is in $/ton unless otherwise specified.
[3] "N" indicates no disposal fee is charged. In this case the ash disposal fee is part of the annual operating cost.

## Appendix D: Heat Recovery Incinerators (Continued)

(24:94-99)

| Location | Size (TPD) | APC[5] Equip | Steam Output (lb/hr) | Full Time People | Capital Cost[6] ($ M) | Annual Cost[6] ($ M) |
|---|---|---|---|---|---|---|
| Deadhorse, AK | 100[1] | ESP | - | 25 | 11.68 | 4.18 |
| Batesville, AR | 100[1] | N | 6,200 | 10 | 2.84 | 0.33 |
| N. Little Rock, AR | 100[2] | N | 15,000 | 18 | 3.52 | 0.42 |
| Perham, MN | 100[1] | ESP | 120,000 | 13 | 8.42 | - |
| Dyersburg, TN | 100[2] | N | 20,000 | 17 | 3.25 | 1.15 |
| Harrisonburg, VA | 100[2] | ESP | 17,000 | 12 | 10.34 | 2.03 |
| Salem, VA | 100[2] | N | 14,000 | 15 | 4.09 | 0.97 |
| Bellingham, WA | 100[1] | ESP | 23,000 | 14 | 7.87 | - |
| Windham, CT | 108[2] | DS/B | 16,800 | 22 | 9.48 | 2.99 |
| Durham, NH | 108[2] | CYC | 20,000 | 14 | 5.11 | 1.05 |
| Miami, OK | 108[2] | N | 23,000 | 10 | 4.25 | 0.48 |
| Cuba, NY | 112[3] | N | 26,000 | 16 | 7.01 | 1.61 |
| Cleburne, TX | 115[3] | ESP | 18,000 | 14 | 6.81 | 1.29 |
| New Richmond, WI | 115[3] | DS/B | 22,500 | 14 | 9.32 | 2.03 |
| Fort Lewis, WA | 120[2] | DS/B | 37,000 | 5 | 11.95 | - |
| Key West, FL | 150[2] | ESP | 42,740 | 24 | 14.53 | 3.14 |
| Winona, MN | 150[2] | DS/B | 36,000 | 20 | 20.90 | 3.11 |
| Pascagoula, MS | 150[2] | ESP | 24,000 | 13 | 8.55 | 1.67 |
| Muskegon, MI | 180[2] | DS/B | 34,000 | 17 | 13.02 | 2.66 |
| Bannock Co., ID | 200 | - | - | - | 11.95 | - |
| Auburn, ME | 200[2] | B | 20,000 | 24 | 16.52 | 3.34 |
| Wilmington, NC | 200[2] | ESP | 54,000 | 31 | 17.70 | 5.02 |
| Portsmouth, NH | 200 | B | - | - | - | - |

[1,2,3,4] 1, 2, 3, or 4 boilers/units, respectively.
[5] APC Equipment: Baghouse (B), Dry Scrubber (DS), Cyclone (CYC), Electrostatic Precipitator (ESP), Wet Scrubber (WS), None (N).
[6] Costs are in 1991 dollars.

Appendix D: Heat Recovery Incinerators (Continued)

(24:94-99)

| Location | Ash/Refuse Ratio (TPD/TPD) | Ash Tip Fee ($/Ton) [1,2] |
|---|---|---|
| Deadhorse, AK | 0.24 | N [3] |
| Batesville, AR | 0.36 | N |
| N. Little Rock, AR | 0.10 | N |
| Perham, MN | 0.26 | 29.38 |
| Dyersburg, TN | 0.20 | N |
| Harrisonburg, VA | 0.40 | N |
| Salem, VA | 0.33 | N |
| Bellingham, WA | 0.40 | N |
| Windham, CT | 0.39 | 10.45 |
| Durham, NH | 0.20 | N |
| Miami, OK | 0.13 | N |
| Cuba, NY | 0.33 | 25.08 |
| Cleburne, TX | 0.20 | N |
| New Richmond, WI | 0.31 | 23.89 |
| Fort Lewis, WA | 0.25 | N |
| Key West, FL | 0.20 | N |
| Winona, MN | 0.46 | 29.86 |
| Pascagoula, MS | 0.31 | 17.92 |
| Muskegon, MI | 0.51 | N |
| Bannock Co., ID | - | - |
| Auburn, ME | 0.65 | 21.50 |
| Wilmington, NC | 0.40 | N |
| Portsmouth, NH | - | N |

[1] Costs are in 1991 dollars.
[2] Ash tip fee is in $/ton unless otherwise specified.
[3] "N" indicates no disposal fee is charged. In this case the ash disposal fee is part of the annual operating cost.

Appendix D: Heat Recovery Incinerators (Continued)

(24:94-99)

| Location | Size (TPD) | APC[5] Equip | Steam Output (lb/hr) | Full Time People | Capital Cost[6] ($ M) | Annual Cost[6] ($ M) |
|---|---|---|---|---|---|---|
| Longbeach, NY | 200[1] | ESP | 58,000 | 28 | 17.92 | - |
| Volney, NY | 200[4] | ESP | 45,000 | 27 | 17.56 | 1.67 |
| Rome, NY | 200[4] | ESP | 26,000 | 33 | 19.01 | 4.18 |
| Pittsfield, MA | 240[2] | ESP | 75,000 | 24 | 15.48 | 3.11 |
| Rutland, VT | 240[2] | WS/ESP | 40,000 | 30 | 28.67 | 2.15 |
| Hampton, SC | 270[2] | ESP | 45,000 | 30 | 12.39 | - |
| Tuscaloosa, AL | 300[2] | ESP | 55,880 | 21 | 12.58 | 1.43 |
| Springfield, MA | 360[3] | DS/B | 85,500 | 30 | 30.27 | 6.81 |
| Edgewood, MD | 360[4] | ESP | 75,000 | 23 | 25.09 | 4.48 |
| Wallingford, CT | 420[3] | DS/B | 105,000 | 24 | 37.93 | 6.57 |
| Lubbock, TX | 425[2] | DS/B | 115,200 | 35 | 25.20 | - |

[1,2,3,4] 1, 2, 3, or 4 boilers/units, respectively.
[5] APC Equipment: Baghouse (B), Dry Scrubber (DS), Cyclone (CYC), Electrostatic Precipitator (ESP), Wet Scrubber (WS), None (N).
[6] Costs are in 1991 dollars.

Appendix D: Heat Recovery Incinerators (Continued)

(24:94-99)

| Location | Ash/Refuse Ratio (TPD/TPD) | Ash Tip Fee ($/Ton) [1,2] |
|---|---|---|
| Longbeach, NY | 0.35 | N [3] |
| Volney, NY | 0.40 | 23.89 |
| Rome, NY | 0.47 | - |
| Pittsfield, MA | 0.42 | N |
| Rutland, VT | 0.48 | N |
| Hampton, SC | 0.40 | - |
| Tuscaloosa, AL | 0.35 | 2.03 |
| Springfield, MA | 0.47 | N |
| Edgewood, MD | 0.41 | N |
| Wallingford, CT | 0.37 | N |
| Lubbock, TX | 0.25 | 5.97 |

[1] Costs are in 1991 dollars.
[2] Ash tip fee is in $/ton unless otherwise specified.
[3] "N" indicates no disposal fee is charged. In this case the ash disposal fee is part of the annual operating cost.

## Appendix E: Area Cost Factors (ACF)

(1)

| Location | ACF | Location | ACF |
|---|---|---|---|
| Atlantic City, NJ | 1.14 | Franklin, KY | 0.95 |
| Sitka, AK | 2.18 | Ft Leonard Wood, MO | 0.98 |
| Center, TX | 0.89 | Livingston, MT | 1.22 |
| Carthage, TX | 0.89 | Fosston, MN | 1.20 |
| Newport News, VA | 0.92 | Alexandria, MN | 1.20 |
| Mayport, FL | 0.89 | Wrightstown, NJ | 1.14 |
| Burley, ID | 1.06 | Almena, WI | 1.04 |
| Frenchville, ME | 1.11 | Fergus Falls, MN | 1.20 |
| Collegeville, MN | 1.20 | Deadhorse, AK | 2.18 |
| Hempfield Twp., PA | 1.01 | Batesville, AR | 0.83 |
| Waxahachie, TX | 0.89 | N. Little Rock, AR | 0.83 |
| Savage, MN | 1.20 | Perham, MN | 1.20 |
| Lewisburg, TN | 0.80 | Dyersburg, TN | 0.80 |
| Juneau, AK | 2.18 | Harrisonburg, VA | 0.92 |
| Red Wing, MN | 1.20 | Salem, VA | 0.92 |

## Appendix E: Area Cost Factors (ACF) (Continued)

| Location | ACF | Location | ACF |
|---|---|---|---|
| Bellingham, WA | 1.00 | Wilmington, NC | 0.81 |
| Windham, CT | 1.19 | Portsmouth, NH | 1.02 |
| Durham, NH | 1.02 | Longbeach, NY | 1.11 |
| Miami, OK | 0.83 | Volney, NY | 1.11 |
| Cuba, NY | 1.11 | Rome, NY | 1.11 |
| Cleburne, TX | 0.89 | Pittsfield, MA | 1.20 |
| New Richmond, WI | 1.04 | Rutland, VT | 1.06 |
| Fort Lewis, WA | 1.00 | Hampton, SC | 0.89 |
| Key West, FL | 0.89 | Tuscaloosa, AL | 0.82 |
| Winona, MN | 1.20 | Springfield, MA | 1.20 |
| Pascagoula, MS | 0.82 | Edgewood, MD | 0.95 |
| Muskegon, MI | 1.12 | Wallingford, CT | 1.19 |
| Bannock Co., ID | 1.06 | Lubbock, TX | 0.89 |
| Auburn, ME | 1.11 | | |

## Appendix E: Area Cost Factors (ACF) (Continued)

| State | ACF | State | ACF |
|---|---|---|---|
| Alabama | 0.82 | Indiana | 1.00 |
| Alaska | 2.18 | Iowa | 1.02 |
| Arizona | 0.95 | Kansas | 0.92 |
| Arkansas | 0.83 | Kentucky | 0.95 |
| California | 1.24 | Louisiana | 0.89 |
| Colorado | 0.97 | Maine | 1.11 |
| Connecticut | 1.19 | Maryland | 0.95 |
| Deleware | 1.00 | Massachusetts | 1.20 |
| Florida | 0.89 | Michigan | 1.12 |
| Georgia | 0.80 | Minnesota | 1.20 |
| Hawaii | 1.46 | Mississippi | 0.82 |
| Idaho | 1.06 | Missouri | 0.98 |
| Illinois | 1.08 | Montana | 1.22 |

## Appendix E: Area Cost Factors (ACF) (Continued)

| State | ACF | State | ACF |
|---|---|---|---|
| Nebraska | 0.93 | Rhode Island | 1.15 |
| Nevada | 1.12 | South Carolina | 0.89 |
| New Hampshire | 1.02 | South Dakota | 1.02 |
| New Jersey | 1.14 | Tennessee | 0.80 |
| New Mexico | 0.95 | Texas | 0.89 |
| New York | 1.11 | Utah | 0.96 |
| North Carolina | 0.81 | Vermont | 1.06 |
| North Dakota | 1.00 | Virginia | 0.92 |
| Ohio<br>(Wright-Patterson) | 0.99<br>1.00 | Washington | 1.00 |
| Oklahoma | 0.83 | West Virginia | 0.99 |
| Oregon | 1.04 | Wisconsin | 1.04 |
| Pennsylvania | 1.01 | Wyoming | 1.08 |
| Washington D.C. | 1.05 | | |

## Appendix F: Regression Analysis Output for Capital Costs

Program: Allyn & Bacon, Quantitative Methods Software Package, accompanying *Quantitative Analysis for Management* (47)

***** Input Data *****

X Variables:
TPD = facility size in tons per day
STM = steam output in tons per hour

Y Variable:
CC = capital cost for HRI with a SDA/FF (in millions of 1991 dollars)

Number of Observations: 8

| Obs. | CC | TPD | STM |
|---|---|---|---|
| 1 | 3.980 | 54.000 | 8400.000 |
| 2 | 2.990 | 38.333 | 7500.000 |
| 3 | 5.980 | 60.000 | 18500.000 |
| 4 | 8.710 | 75.000 | 18000.000 |
| 5 | 5.810 | 90.000 | 17000.000 |
| 6 | 8.410 | 120.000 | 28500.000 |
| 7 | 10.620 | 140.000 | 35000.000 |
| 8 | 14.160 | 212.500 | 57600.000 |

***** Program Output *****

| Parameter | Coefficient | SE B | t |
|---|---|---|---|
| Intercept | 2.4991 | 1.1530 | 2.1675 |
| b 1 | 0.0009 | 0.0458 | 0.0188 |
| b 2 | 0.0002 | 0.0002 | 1.3214 |

Coefficient of determination : 0.9139
Correlation coefficient : 0.9560
Standard Error : 1.2738

## Appendix F: Regression Analysis Output for Capital Costs (Continued)

Prediction Error

| Obs. | Observed Value | Predicted Value | Residual |
|---|---|---|---|
| 1 | 3.980 | 4.309 | -0.329 |
| 2 | 2.990 | 4.106 | -1.116 |
| 3 | 5.980 | 6.434 | -0.454 |
| 4 | 8.710 | 6.342 | 2.368 |
| 5 | 5.810 | 6.145 | -0.335 |
| 6 | 8.410 | 8.585 | -0.175 |
| 7 | 10.620 | 9.966 | 0.654 |
| 8 | 14.160 | 14.773 | -0.613 |

Mean Absolute Deviation (MAD) : 0.8633

ANOVA Table

| Source of Variation | SS | df | MS |
|---|---|---|---|
| Regression | 86.111 | 2 | 43.056 |
| Residual | 8.113 | 5 | 1.623 |
| Total | 94.225 | 7 | |

F* = 26.533

***** End of Output *****

## Appendix G: Regression Analysis Output for Annual Costs

Program: Allyn & Bacon, Quantitative Methods Software Package, accompanying *Quantitative Analysis for Management* (47)

***** Input Data *****

X Variables:
STM = steam output in tons per hour
PN = number of full-time employees
TPD = facility size in tons per day

Y Variable:
AC = annual cost for HRI with a SDA/FF (in millions of 1991 dollars)

Number of Observations: 6

| Obs. | AC | STM | PN | TPD |
|---|---|---|---|---|
| 1 | 1.320 | 8400.000 | 11.000 | 54.000 |
| 2 | 0.750 | 7500.000 | 4.670 | 38.333 |
| 3 | 1.610 | 18000.000 | 10.000 | 75.000 |
| 4 | 1.190 | 17000.000 | 8.500 | 90.000 |
| 5 | 1.890 | 28500.000 | 10.000 | 120.000 |
| 6 | 1.840 | 35000.000 | 8.000 | 140.000 |

***** Program Output *****

| Parameter | Coefficient | SE B | t |
|---|---|---|---|
| Intercept | 0.1479 | 0.0828 | 1.7853 |
| b 1 | 0.0001 | 0.0000 | 7.3121 |
| b 2 | 0.1110 | 0.0094 | 11.7996 |
| b 3 | -0.0126 | 0.0029 | -4.3585 |

Coefficient of determination : 0.9961
Correlation coefficient : 0.9981
Standard Error : 0.0427

## Appendix G: Regression Analysis Output for Annual Costs (Continued)

Prediction Error

| Obs. | Observed Value | Predicted Value | Residual |
|---|---|---|---|
| 1 | 1.320 | 1.309 | 0.011 |
| 2 | 0.750 | 0.737 | 0.013 |
| 3 | 1.610 | 1.641 | -0.031 |
| 4 | 1.190 | 1.212 | -0.022 |
| 5 | 1.890 | 1.848 | 0.042 |
| 6 | 1.840 | 1.853 | -0.013 |

Mean Absolute Deviation (MAD) : 0.0264

ANOVA Table

| Source of Variation | SS | df | MS |
|---|---|---|---|
| Regression | 0.940 | 3 | 0.313 |
| Residual | 0.004 | 2 | 0.002 |
| Total | 0.944 | 5 | |

F* = 171.617

***** End of Output *****

## Appendix H: Life-Cycle Cost Computer Input

(41)

```
***************************************************************
*   N I S T   B L C C   I N P U T   D A T A   L I S T I N G   *
***************************************************************

FILE NAME: DONOTHNG
FILE LAST MODIFIED ON 07-11-1992/09:04:22
PROJECT TITLE: Do Nothing
COMMENT: Let existing heat plant operate as is

GENERAL DATA:
-------------
ANALYSIS TYPE: Generic LCC Analysis--No Tax Analysis
BASE DATE FOR LCC ANALYSIS: 1992
STUDY PERIOD:  26 YEARS
PLANNING/CONSTRUCTION PERIOD:  0 YEARS
OCCUPANCY DATE: 1992
DISCOUNT AND INTEREST RATES Real (exclusive of general
inflation)
DISCOUNT RATE:  7.0%

CAPITAL ASSET COST DATA:
------------------------
INITIAL COST ($)                           0
EXPECTED COMPONENT LIFE(YRS)              26
RESALE VALUE FACTOR                    0.00%
AVG PRICE ESC RATE (OCCUPANCY)         0.00%
Escalation rates do not include general inflation
NUMBER OF REPLACEMENTS                     0

NO REPLACEMENTS

OPERATING AND MAINTENANCE COST DATA:
------------------------------------
ANNUAL RECUR O&M COST ($): 945,000
ESCALATION RATE FOR O&M:     0.00%
Escalation rates do not include general inflation

NON-AN RECURRING O&M COSTS ($):
 YR   AMOUNT

ENERGY COST DATA:
-----------------
NUMBER OF ENERGY TYPES = 1
DOE energy price escalation rates filename: ENCOST92.RAN
DOE region (state code): 2 (OH)
DOE rate schedule type: Industrial
DOE energy price escalation rates used with Energy Type(s) 1
```

Appendix H: Life-Cycle Cost Computer Input (Continued)

| | |
|---|---|
| | TYPE 1 |
| ENERGY TYPE: | Coal |
| AVG ANNUAL CONSUMPTION: | 12635 |
| UNITS: | TONS |
| PRICE PER UNIT ($): | 58.760 |
| ANNUAL DEMAND CHARGE ($): | 0.00 |
| ESCALATION RATES BY YEAR: | Escalation rates do not include |

general inflation

| | |
|---|---|
| 1992 | 1.68 |
| 1993 | 2.64 |
| 1994 | 1.64 |
| 1995 | 0.24 |
| 1996 | 0.64 |
| 1997 | 0.63 |
| 1998 | 0.34 |
| 1999 | 0.79 |
| 2000 | 1.53 |
| 2001 | 1.21 |
| 2002 | 1.55 |
| 2003 | 1.87 |
| 2004 | 2.18 |
| 2005 | 2.23 |
| 2006 | 1.77 |
| 2007 | 2.56 |
| 2008 | 2.21 |
| 2009 | 1.09 |
| 2010 | 1.81 |
| 2011 | 0.50 |
| 2012 | 0.50 |
| 2013 | 0.50 |
| 2014 | 0.50 |
| 2015 | 0.49 |
| 2016 | 0.49 |
| 2017 | 0.00 |

```
*************************************************************
*   N I S T   B L C C   I N P U T   D A T A   L I S T I N G   *
*************************************************************

FILE NAME: REPLACE
FILE LAST MODIFIED ON 07-11-1992/09:00:34
PROJECT TITLE: Rpl w/Gas
COMMENT: Replace existing boilers with nat gas fired units

GENERAL DATA:
-------------
ANALYSIS TYPE: Generic LCC Analysis--No Tax Analysis
BASE DATE FOR LCC ANALYSIS: 1992
STUDY PERIOD:  26 YEARS
PLANNING/CONSTRUCTION PERIOD:  1 YEARS
OCCUPANCY DATE: 1993
DISCOUNT AND INTEREST RATES Real (exclusive of general
inflation)
DISCOUNT RATE:  7.0%

CAPITAL ASSET COST DATA:
------------------------
INITIAL COST ($)                          1,200,000
EXPECTED COMPONENT LIFE(YRS)                     26
RESALE VALUE FACTOR                          10.00%
AVG PRICE ESC RATE(PLAN/CONST)                0.00%
AVG PRICE ESC RATE (OCCUPANCY)                0.00%
Escalation rates do not include general inflation
NUMBER OF REPLACEMENTS                            0

COST-PHASING SCHEDULE BY YEAR OF CONSTRUCTION AND AT
OCCUPANCY:
                                  1         100.00%
                   AT OCCUPANCY               0.00%

NO REPLACEMENTS

OPERATING AND MAINTENANCE COST DATA:
------------------------------------
ANNUAL RECUR O&M COST ($): 945,000
ESCALATION RATE FOR O&M:      0.00%
Escalation rates do not include general inflation

NON-AN RECURRING O&M COSTS ($):
 YR   AMOUNT
```

ENERGY COST DATA:
-----------------
NUMBER OF ENERGY TYPES = 1
DOE energy price escalation rates filename: ENCOST92.RAN
DOE region (state code): 2 (OH)
DOE rate schedule type: Industrial
DOE energy price escalation rates used with Energy Type(s) 1

| | TYPE 1 |
|---|---|
| ENERGY TYPE: | Natural Gas |
| AVG ANNUAL CONSUMPTION: | 3285000 |
| UNITS: | THERMS |
| PRICE PER UNIT ($): | 0.400 |
| ANNUAL DEMAND CHARGE ($): | 0.00 |
| ESCALATION RATES BY YEAR: | Escalation rates do not include general inflation |

| | |
|---|---|
| 1992 | -1.95 |
| 1993 | 1.84 |
| 1994 | 0.72 |
| 1995 | -0.01 |
| 1996 | -0.00 |
| 1997 | 0.72 |
| 1998 | 1.09 |
| 1999 | 4.34 |
| 2000 | 4.86 |
| 2001 | 5.63 |
| 2002 | 7.23 |
| 2003 | 5.27 |
| 2004 | 3.90 |
| 2005 | 5.63 |
| 2006 | 4.06 |
| 2007 | 3.90 |
| 2008 | 2.34 |
| 2009 | 1.37 |
| 2010 | 2.93 |
| 2011 | 1.46 |
| 2012 | 2.02 |
| 2013 | 1.98 |
| 2014 | 1.66 |
| 2015 | 1.63 |
| 2016 | 1.07 |
| 2017 | 1.33 |

```
*************************************************************
*  N I S T  B L C C  I N P U T  D A T A  L I S T I N G    *
*************************************************************

FILE NAME: SDAFF
FILE LAST MODIFIED ON 07-11-1992/09:01:30
PROJECT TITLE: SDA/FF
COMMENT: Install 100 TPD mod HRI with SDA/FF APC equipment

GENERAL DATA:
-------------
ANALYSIS TYPE: Generic LCC Analysis--No Tax Analysis
BASE DATE FOR LCC ANALYSIS: 1992
STUDY PERIOD:  26 YEARS
PLANNING/CONSTRUCTION PERIOD:  1 YEARS
OCCUPANCY DATE: 1993
DISCOUNT AND INTEREST RATES Real (exclusive of general
inflation)
DISCOUNT RATE:  7.0%

CAPITAL ASSET COST DATA:
------------------------
INITIAL COST ($)                      8,179,000
EXPECTED COMPONENT LIFE(YRS)                 26
RESALE VALUE FACTOR                      10.00%
AVG PRICE ESC RATE(PLAN/CONST)            0.00%
AVG PRICE ESC RATE (OCCUPANCY)            0.00%
Escalation rates do not include general inflation
NUMBER OF REPLACEMENTS                        0

COST-PHASING SCHEDULE BY YEAR OF CONSTRUCTION AND AT
OCCUPANCY:
                               1        100.00%
                   AT OCCUPANCY           0.00%

NO REPLACEMENTS

OPERATING AND MAINTENANCE COST DATA:
------------------------------------
ANNUAL RECUR O&M COST ($):  1,860,000
ESCALATION RATE FOR O&M:      0.00%
Escalation rates do not include general inflation

NON-AN RECURRING O&M COSTS ($):
 YR   AMOUNT

ENERGY COST DATA:
-----------------
NUMBER OF ENERGY TYPES = 0
```

```
*************************************************************
*   N I S T   B L C C   I N P U T   D A T A   L I S T I N G   *
*************************************************************

FILE NAME: SDAESP
FILE LAST MODIFIED ON 07-11-1992/09:01:01
PROJECT TITLE: SDA/ESP
COMMENT: Install 100 TPD mod HRI with SDA/ESP APC equipment

GENERAL DATA:
-------------
ANALYSIS TYPE: Generic LCC Analysis--No Tax Analysis
BASE DATE FOR LCC ANALYSIS: 1992
STUDY PERIOD:  26 YEARS
PLANNING/CONSTRUCTION PERIOD:  1 YEARS
OCCUPANCY DATE: 1993
DISCOUNT AND INTEREST RATES Real (exclusive of general
inflation)
DISCOUNT RATE:  7.0%

CAPITAL ASSET COST DATA:
------------------------
INITIAL COST ($)                  7,560,000
EXPECTED COMPONENT LIFE(YRS)             26
RESALE VALUE FACTOR                  10.00%
AVG PRICE ESC RATE(PLAN/CONST)        0.00%
AVG PRICE ESC RATE (OCCUPANCY)        0.00%
Escalation rates do not include general inflation
NUMBER OF REPLACEMENTS                    0

COST-PHASING SCHEDULE BY YEAR OF CONSTRUCTION AND AT
OCCUPANCY:
                             1       100.00%
                   AT OCCUPANCY        0.00%

NO REPLACEMENTS

OPERATING AND MAINTENANCE COST DATA:
------------------------------------
ANNUAL RECUR O&M COST ($):  1,720,000
ESCALATION RATE FOR O&M:      0.00%
Escalation rates do not include general inflation

NON-AN RECURRING O&M COSTS ($):
 YR   AMOUNT

ENERGY COST DATA:
-----------------
NUMBER OF ENERGY TYPES = 0
```

(41)

```
**************************************************************************
*      N I S T   B L C C   C A S H   F L O W   A N A L Y S I S           *
**************************************************************************
```

PROJECT NAME: Do Nothing
COMMENT: Let existing heat plant operate as is
RUN DATE: 07-11-1992 09:25:09
INPUT DATA FILE: DONOTHNG.DAT, LAST MODIFIED 07-11-1992/09:04:22
STUDY PERIOD: 26 YEARS (1992 THROUGH 2017)
ANALYSIS TYPE: Generic LCC Analysis--No Tax Analysis
All costs in constant 1992 dollars (i.e., excluding general inflation)

INITIAL CAPITAL COSTS

| YEAR | TOTAL (BY YEAR) |
|---|---|
| 1992 | 0 |
| TOTAL: | 0 |

CAPITAL INVESTMENT COSTS

| YEAR | INIT CAPITAL INVESTMENT | CAPITAL REPLACEMENTS | CAPITAL DISPOSAL | TOTAL CAP. INVESTMENT |
|---|---|---|---|---|
| 1992 | 0 | 0 | 0 | 0 |
| 1993 | 0 | 0 | 0 | 0 |
| 1994 | 0 | 0 | 0 | 0 |
| 1995 | 0 | 0 | 0 | 0 |
| 1996 | 0 | 0 | 0 | 0 |
| 1997 | 0 | 0 | 0 | 0 |
| 1998 | 0 | 0 | 0 | 0 |
| 1999 | 0 | 0 | 0 | 0 |
| 2000 | 0 | 0 | 0 | 0 |
| 2001 | 0 | 0 | 0 | 0 |
| 2002 | 0 | 0 | 0 | 0 |
| 2003 | 0 | 0 | 0 | 0 |
| 2004 | 0 | 0 | 0 | 0 |
| 2005 | 0 | 0 | 0 | 0 |
| 2006 | 0 | 0 | 0 | 0 |
| 2007 | 0 | 0 | 0 | 0 |
| 2008 | 0 | 0 | 0 | 0 |
| 2009 | 0 | 0 | 0 | 0 |
| 2010 | 0 | 0 | 0 | 0 |
| 2011 | 0 | 0 | 0 | 0 |
| 2012 | 0 | 0 | 0 | 0 |
| 2013 | 0 | 0 | 0 | 0 |
| 2014 | 0 | 0 | 0 | 0 |
| 2015 | 0 | 0 | 0 | 0 |
| 2016 | 0 | 0 | 0 | 0 |
| 2017 | 0 | 0 | 0 | 0 |
| TOTAL | 0 | 0 | 0 | 0 |

Appendix I: Cash Flows for Life-Cycle Cost Analysis (Continued)

OPERATING-RELATED COSTS DURING OCCUPANCY

| YEAR | - OPERATING AND MAINTENANCE COSTS - AN RECURRING | NON-AN REC | ENERGY | TOTAL OPER. COST |
|---|---|---|---|---|
| 1992 | 945,000 | 0 | 754,910 | 1,699,910 |
| 1993 | 945,000 | 0 | 774,823 | 1,719,823 |
| 1994 | 945,000 | 0 | 787,539 | 1,732,539 |
| 1995 | 945,000 | 0 | 789,399 | 1,734,400 |
| 1996 | 945,000 | 0 | 794,422 | 1,739,422 |
| 1997 | 945,000 | 0 | 799,388 | 1,744,388 |
| 1998 | 945,000 | 0 | 802,084 | 1,747,084 |
| 1999 | 945,000 | 0 | 808,439 | 1,753,439 |
| 2000 | 945,000 | 0 | 820,841 | 1,765,841 |
| 2001 | 945,000 | 0 | 830,753 | 1,775,753 |
| 2002 | 945,000 | 0 | 843,614 | 1,788,614 |
| 2003 | 945,000 | 0 | 859,429 | 1,804,429 |
| 2004 | 945,000 | 0 | 878,160 | 1,823,160 |
| 2005 | 945,000 | 0 | 897,778 | 1,842,778 |
| 2006 | 945,000 | 0 | 913,637 | 1,858,637 |
| 2007 | 945,000 | 0 | 937,001 | 1,882,001 |
| 2008 | 945,000 | 0 | 957,744 | 1,902,744 |
| 2009 | 945,000 | 0 | 968,197 | 1,913,197 |
| 2010 | 945,000 | 0 | 985,678 | 1,930,678 |
| 2011 | 945,000 | 0 | 990,650 | 1,935,650 |
| 2012 | 945,000 | 0 | 995,616 | 1,940,616 |
| 2013 | 945,000 | 0 | 1,000,588 | 1,945,588 |
| 2014 | 945,000 | 0 | 1,005,553 | 1,950,553 |
| 2015 | 945,000 | 0 | 1,010,519 | 1,955,519 |
| 2016 | 945,000 | 0 | 1,015,491 | 1,960,491 |
| 2017 | 945,000 | 0 | 1,015,491 | 1,960,491 |
| TOTAL | 24,570,000 | 0 | 23,237,744 | 47,807,744 |

SUM OF ALL CASH FLOWS

| YEAR | CAPITAL INVESTMENT | OPERATING COSTS | TOTAL COST |
|---|---|---|---|
| 1992 | 0 | 1,699,910 | 1,699,910 |
| 1993 | 0 | 1,719,823 | 1,719,823 |
| 1994 | 0 | 1,732,539 | 1,732,539 |
| 1995 | 0 | 1,734,400 | 1,734,400 |
| 1996 | 0 | 1,739,422 | 1,739,422 |
| 1997 | 0 | 1,744,388 | 1,744,388 |
| 1998 | 0 | 1,747,084 | 1,747,084 |
| 1999 | 0 | 1,753,439 | 1,753,439 |
| 2000 | 0 | 1,765,841 | 1,765,841 |
| 2001 | 0 | 1,775,753 | 1,775,753 |
| 2002 | 0 | 1,788,614 | 1,788,614 |
| 2003 | 0 | 1,804,429 | 1,804,429 |
| 2004 | 0 | 1,823,160 | 1,823,160 |
| 2005 | 0 | 1,842,778 | 1,842,778 |
| 2006 | 0 | 1,858,637 | 1,858,637 |
| 2007 | 0 | 1,882,001 | 1,882,001 |
| 2008 | 0 | 1,902,744 | 1,902,744 |
| 2009 | 0 | 1,913,197 | 1,913,197 |
| 2010 | 0 | 1,930,678 | 1,930,678 |
| 2011 | 0 | 1,935,650 | 1,935,650 |
| 2012 | 0 | 1,940,616 | 1,940,616 |
| 2013 | 0 | 1,945,588 | 1,945,588 |
| 2014 | 0 | 1,950,553 | 1,950,553 |
| 2015 | 0 | 1,955,519 | 1,955,519 |
| 2016 | 0 | 1,960,491 | 1,960,491 |
| 2017 | 0 | 1,960,491 | 1,960,491 |
| TOTAL | 0 | 47,807,744 | 47,807,744 |

Appendix I: Cash Flows for Life-Cycle Cost Analysis (Continued)

```
*****************************************************************************
*     N I S T   B L C C   C A S H   F L O W   A N A L Y S I S             *
*****************************************************************************
```

PROJECT NAME: Rpl w/Gas
COMMENT: Replace existing boilers with nat gas fired units
RUN DATE: 07-11-1992 09:25:15
INPUT DATA FILE: REPLACE.DAT, LAST MODIFIED 07-11-1992/09:00:34
STUDY PERIOD: 26 YEARS (1992 THROUGH 2017)
PLAN/CONSTR. PERIOD: 1 YEARS (1992 THROUGH 1992)
OCCUPANCY PERIOD: 25 YEARS (1993 THROUGH 2017)
ANALYSIS TYPE: Generic LCC Analysis--No Tax Analysis
All costs in constant 1992 dollars (i.e., excluding general inflation)

INITIAL CAPITAL COSTS
(AS INCURRED DURING PLANNING/CONSTRUCTION PERIOD AND AT OCCUPANCY)

| YEAR | TOTAL (BY YEAR) |
|---|---|
| 1992 | 1200000 |
| 1993 | 0 |
| TOTAL: | 1200000 |

CAPITAL INVESTMENT COSTS

| YEAR | INIT CAPITAL INVESTMENT | CAPITAL REPLACEMENTS | CAPITAL DISPOSAL | TOTAL CAP. INVESTMENT |
|---|---|---|---|---|
| 1992 | 1,200,000 | 0 | 0 | 1,200,000 |
| 1993 | 0 | 0 | 0 | 0 |
| 1994 | 0 | 0 | 0 | 0 |
| 1995 | 0 | 0 | 0 | 0 |
| 1996 | 0 | 0 | 0 | 0 |
| 1997 | 0 | 0 | 0 | 0 |
| 1998 | 0 | 0 | 0 | 0 |
| 1999 | 0 | 0 | 0 | 0 |
| 2000 | 0 | 0 | 0 | 0 |
| 2001 | 0 | 0 | 0 | 0 |
| 2002 | 0 | 0 | 0 | 0 |
| 2003 | 0 | 0 | 0 | 0 |
| 2004 | 0 | 0 | 0 | 0 |
| 2005 | 0 | 0 | 0 | 0 |
| 2006 | 0 | 0 | 0 | 0 |
| 2007 | 0 | 0 | 0 | 0 |
| 2008 | 0 | 0 | 0 | 0 |
| 2009 | 0 | 0 | 0 | 0 |
| 2010 | 0 | 0 | 0 | 0 |
| 2011 | 0 | 0 | 0 | 0 |
| 2012 | 0 | 0 | 0 | 0 |
| 2013 | 0 | 0 | 0 | 0 |
| 2014 | 0 | 0 | 0 | 0 |
| 2015 | 0 | 0 | 0 | 0 |
| 2016 | 0 | 0 | 0 | 0 |
| 2017 | 0 | 0 | 120,000 | -120,000 |
| TOTAL | 1,200,000 | 0 | 120,000 | 1,080,000 |

## Appendix I: Cash Flows for Life-Cycle Cost Analysis (Continued)

OPERATING-RELATED COSTS DURING OCCUPANCY

| YEAR | - OPERATING AND MAINTENANCE COSTS - AN RECURRING | NON-AN REC | ENERGY | TOTAL OPER. COST |
|---|---|---|---|---|
| 1993 | 945,000 | 0 | 1,312,074 | 2,257,074 |
| 1994 | 945,000 | 0 | 1,321,507 | 2,266,507 |
| 1995 | 945,000 | 0 | 1,321,322 | 2,266,322 |
| 1996 | 945,000 | 0 | 1,321,264 | 2,266,264 |
| 1997 | 945,000 | 0 | 1,330,814 | 2,275,814 |
| 1998 | 945,000 | 0 | 1,345,274 | 2,290,274 |
| 1999 | 945,000 | 0 | 1,403,723 | 2,348,723 |
| 2000 | 945,000 | 0 | 1,471,882 | 2,416,882 |
| 2001 | 945,000 | 0 | 1,554,694 | 2,499,695 |
| 2002 | 945,000 | 0 | 1,667,048 | 2,612,048 |
| 2003 | 945,000 | 0 | 1,754,963 | 2,699,963 |
| 2004 | 945,000 | 0 | 1,823,340 | 2,768,340 |
| 2005 | 945,000 | 0 | 1,925,979 | 2,870,979 |
| 2006 | 945,000 | 0 | 2,004,125 | 2,949,125 |
| 2007 | 945,000 | 0 | 2,082,271 | 3,027,271 |
| 2008 | 945,000 | 0 | 2,131,031 | 3,076,031 |
| 2009 | 945,000 | 0 | 2,160,299 | 3,105,299 |
| 2010 | 945,000 | 0 | 2,223,692 | 3,168,692 |
| 2011 | 945,000 | 0 | 2,256,200 | 3,201,200 |
| 2012 | 945,000 | 0 | 2,301,716 | 3,246,716 |
| 2013 | 945,000 | 0 | 2,347,228 | 3,292,228 |
| 2014 | 945,000 | 0 | 2,386,240 | 3,331,240 |
| 2015 | 945,000 | 0 | 2,425,252 | 3,370,252 |
| 2016 | 945,000 | 0 | 2,451,260 | 3,396,260 |
| 2017 | 945,000 | 0 | 2,483,772 | 3,428,772 |
| TOTAL | 23,625,000 | 0 | 46,806,968 | 70,431,968 |

Appendix I: Cash Flows for Life-Cycle Cost Analysis (Continued)

SUM OF ALL CASH FLOWS

| YEAR | CAPITAL INVESTMENT | OPERATING COSTS | TOTAL COST |
|---|---|---|---|
| 1992 | 1,200,000 | 0 | 1,200,000 |
| 1993 | 0 | 2,257,074 | 2,257,074 |
| 1994 | 0 | 2,266,507 | 2,266,507 |
| 1995 | 0 | 2,266,322 | 2,266,322 |
| 1996 | 0 | 2,266,264 | 2,266,264 |
| 1997 | 0 | 2,275,814 | 2,275,814 |
| 1998 | 0 | 2,290,274 | 2,290,274 |
| 1999 | 0 | 2,348,723 | 2,348,723 |
| 2000 | 0 | 2,416,882 | 2,416,882 |
| 2001 | 0 | 2,499,695 | 2,499,695 |
| 2002 | 0 | 2,612,048 | 2,612,048 |
| 2003 | 0 | 2,699,963 | 2,699,963 |
| 2004 | 0 | 2,768,340 | 2,768,340 |
| 2005 | 0 | 2,870,979 | 2,870,979 |
| 2006 | 0 | 2,949,125 | 2,949,125 |
| 2007 | 0 | 3,027,271 | 3,027,271 |
| 2008 | 0 | 3,076,031 | 3,076,031 |
| 2009 | 0 | 3,105,299 | 3,105,299 |
| 2010 | 0 | 3,168,692 | 3,168,692 |
| 2011 | 0 | 3,201,200 | 3,201,200 |
| 2012 | 0 | 3,246,716 | 3,246,716 |
| 2013 | 0 | 3,292,228 | 3,292,228 |
| 2014 | 0 | 3,331,240 | 3,331,240 |
| 2015 | 0 | 3,370,252 | 3,370,252 |
| 2016 | 0 | 3,396,260 | 3,396,260 |
| 2017 | -120,000 | 3,428,772 | 3,308,772 |
| TOTAL | 1,080,000 | 70,431,968 | 71,511,968 |

```
*************************************************************************
*      N I S T   B L C C   C A S H   F L O W   A N A L Y S I S          *
*************************************************************************
```

PROJECT NAME: SDA/FF
COMMENT: Install 100 TPD mod HRI with SDA/FF APC equipment
RUN DATE: 07-11-1992 09:25:27
INPUT DATA FILE: SDAFF.DAT, LAST MODIFIED 07-11-1992/09:01:30
STUDY PERIOD: 26 YEARS (1992 THROUGH 2017)
PLAN/CONSTR. PERIOD: 1 YEARS (1992 THROUGH 1992)
OCCUPANCY PERIOD: 25 YEARS (1993 THROUGH 2017)
ANALYSIS TYPE: Generic LCC Analysis--No Tax Analysis
All costs in constant 1992 dollars (i.e., excluding general inflation)

INITIAL CAPITAL COSTS
(AS INCURRED DURING PLANNING/CONSTRUCTION PERIOD AND AT OCCUPANCY)

| YEAR | TOTAL (BY YEAR) |
|---|---|
| 1992 | 8179000 |
| 1993 | 0 |
| TOTAL: | 8179000 |

CAPITAL INVESTMENT COSTS

| YEAR | INIT CAPITAL INVESTMENT | CAPITAL REPLACEMENTS | CAPITAL DISPOSAL | TOTAL CAP. INVESTMENT |
|---|---|---|---|---|
| 1992 | 8,179,000 | 0 | 0 | 8,179,000 |
| 1993 | 0 | 0 | 0 | 0 |
| 1994 | 0 | 0 | 0 | 0 |
| 1995 | 0 | 0 | 0 | 0 |
| 1996 | 0 | 0 | 0 | 0 |
| 1997 | 0 | 0 | 0 | 0 |
| 1998 | 0 | 0 | 0 | 0 |
| 1999 | 0 | 0 | 0 | 0 |
| 2000 | 0 | 0 | 0 | 0 |
| 2001 | 0 | 0 | 0 | 0 |
| 2002 | 0 | 0 | 0 | 0 |
| 2003 | 0 | 0 | 0 | 0 |
| 2004 | 0 | 0 | 0 | 0 |
| 2005 | 0 | 0 | 0 | 0 |
| 2006 | 0 | 0 | 0 | 0 |
| 2007 | 0 | 0 | 0 | 0 |
| 2008 | 0 | 0 | 0 | 0 |
| 2009 | 0 | 0 | 0 | 0 |
| 2010 | 0 | 0 | 0 | 0 |
| 2011 | 0 | 0 | 0 | 0 |
| 2012 | 0 | 0 | 0 | 0 |
| 2013 | 0 | 0 | 0 | 0 |
| 2014 | 0 | 0 | 0 | 0 |
| 2015 | 0 | 0 | 0 | 0 |
| 2016 | 0 | 0 | 0 | 0 |
| 2017 | 0 | 0 | 817,900 | -817,900 |
| TOTAL | 8,179,000 | 0 | 817,900 | 7,361,100 |

Appendix I: Cash Flows for Life-Cycle Cost Analysis (Continued)

OPERATING-RELATED COSTS DURING OCCUPANCY

| YEAR | - OPERATING AND MAINTENANCE COSTS - AN RECURRING | NON-AN REC | ENERGY | TOTAL OPER. COST |
|---|---|---|---|---|
| 1993 | 1,860,000 | 0 | 0 | 1,860,000 |
| 1994 | 1,860,000 | 0 | 0 | 1,860,000 |
| 1995 | 1,860,000 | 0 | 0 | 1,860,000 |
| 1996 | 1,860,000 | 0 | 0 | 1,860,000 |
| 1997 | 1,860,000 | 0 | 0 | 1,860,000 |
| 1998 | 1,860,000 | 0 | 0 | 1,860,000 |
| 1999 | 1,860,000 | 0 | 0 | 1,860,000 |
| 2000 | 1,860,000 | 0 | 0 | 1,860,000 |
| 2001 | 1,860,000 | 0 | 0 | 1,860,000 |
| 2002 | 1,860,000 | 0 | 0 | 1,860,000 |
| 2003 | 1,860,000 | 0 | 0 | 1,860,000 |
| 2004 | 1,860,000 | 0 | 0 | 1,860,000 |
| 2005 | 1,860,000 | 0 | 0 | 1,860,000 |
| 2006 | 1,860,000 | 0 | 0 | 1,860,000 |
| 2007 | 1,860,000 | 0 | 0 | 1,860,000 |
| 2008 | 1,860,000 | 0 | 0 | 1,860,000 |
| 2009 | 1,860,000 | 0 | 0 | 1,860,000 |
| 2010 | 1,860,000 | 0 | 0 | 1,860,000 |
| 2011 | 1,860,000 | 0 | 0 | 1,860,000 |
| 2012 | 1,860,000 | 0 | 0 | 1,860,000 |
| 2013 | 1,860,000 | 0 | 0 | 1,860,000 |
| 2014 | 1,860,000 | 0 | 0 | 1,860,000 |
| 2015 | 1,860,000 | 0 | 0 | 1,860,000 |
| 2016 | 1,860,000 | 0 | 0 | 1,860,000 |
| 2017 | 1,860,000 | 0 | 0 | 1,860,000 |
| TOTAL | 46,500,000 | 0 | 0 | 46,500,000 |

Appendix I: Cash Flows for Life-Cycle Cost Analysis (Continued)

SUM OF ALL CASH FLOWS

| YEAR | CAPITAL INVESTMENT | OPERATING COSTS | TOTAL COST |
|---|---|---|---|
| 1992 | 8,179,000 | 0 | 8,179,000 |
| 1993 | 0 | 1,860,000 | 1,860,000 |
| 1994 | 0 | 1,860,000 | 1,860,000 |
| 1995 | 0 | 1,860,000 | 1,860,000 |
| 1996 | 0 | 1,860,000 | 1,860,000 |
| 1997 | 0 | 1,860,000 | 1,860,000 |
| 1998 | 0 | 1,860,000 | 1,860,000 |
| 1999 | 0 | 1,860,000 | 1,860,000 |
| 2000 | 0 | 1,860,000 | 1,860,000 |
| 2001 | 0 | 1,860,000 | 1,860,000 |
| 2002 | 0 | 1,860,000 | 1,860,000 |
| 2003 | 0 | 1,860,000 | 1,860,000 |
| 2004 | 0 | 1,860,000 | 1,860,000 |
| 2005 | 0 | 1,860,000 | 1,860,000 |
| 2006 | 0 | 1,860,000 | 1,860,000 |
| 2007 | 0 | 1,860,000 | 1,860,000 |
| 2008 | 0 | 1,860,000 | 1,860,000 |
| 2009 | 0 | 1,860,000 | 1,860,000 |
| 2010 | 0 | 1,860,000 | 1,860,000 |
| 2011 | 0 | 1,860,000 | 1,860,000 |
| 2012 | 0 | 1,860,000 | 1,860,000 |
| 2013 | 0 | 1,860,000 | 1,860,000 |
| 2014 | 0 | 1,860,000 | 1,860,000 |
| 2015 | 0 | 1,860,000 | 1,860,000 |
| 2016 | 0 | 1,860,000 | 1,860,000 |
| 2017 | -817,900 | 1,860,000 | 1,042,100 |
| TOTAL | 7,361,100 | 46,500,000 | 53,861,100 |

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******************************************************************************
*       N I S T   B L C C   C A S H   F L O W   A N A L Y S I S              *
******************************************************************************

PROJECT NAME: SDA/ESP
COMMENT: Install 100 TPD mod HRI with SDA/ESP APC equipment
RUN DATE: 07-11-1992 09:25:22
INPUT DATA FILE: SDAESP.DAT, LAST MODIFIED 07-11-1992/09:01:01
STUDY PERIOD:          26 YEARS (1992 THROUGH 2017)
PLAN/CONSTR. PERIOD:    1 YEARS (1992 THROUGH 1992)
OCCUPANCY PERIOD:      25 YEARS (1993 THROUGH 2017)
ANALYSIS TYPE: Generic LCC Analysis--No Tax Analysis
All costs in constant 1992 dollars (i.e., excluding general inflation)
```

INITIAL CAPITAL COSTS
(AS INCURRED DURING PLANNING/CONSTRUCTION PERIOD AND AT OCCUPANCY)

| YEAR | TOTAL (BY YEAR) |
|---|---|
| 1992 | 7560000 |
| 1993 | 0 |
| TOTAL: | 7560000 |

CAPITAL INVESTMENT COSTS

| YEAR | INIT CAPITAL INVESTMENT | CAPITAL REPLACEMENTS | CAPITAL DISPOSAL | TOTAL CAP. INVESTMENT |
|---|---|---|---|---|
| 1992 | 7,560,000 | 0 | 0 | 7,560,000 |
| 1993 | 0 | 0 | 0 | 0 |
| 1994 | 0 | 0 | 0 | 0 |
| 1995 | 0 | 0 | 0 | 0 |
| 1996 | 0 | 0 | 0 | 0 |
| 1997 | 0 | 0 | 0 | 0 |
| 1998 | 0 | 0 | 0 | 0 |
| 1999 | 0 | 0 | 0 | 0 |
| 2000 | 0 | 0 | 0 | 0 |
| 2001 | 0 | 0 | 0 | 0 |
| 2002 | 0 | 0 | 0 | 0 |
| 2003 | 0 | 0 | 0 | 0 |
| 2004 | 0 | 0 | 0 | 0 |
| 2005 | 0 | 0 | 0 | 0 |
| 2006 | 0 | 0 | 0 | 0 |
| 2007 | 0 | 0 | 0 | 0 |
| 2008 | 0 | 0 | 0 | 0 |
| 2009 | 0 | 0 | 0 | 0 |
| 2010 | 0 | 0 | 0 | 0 |
| 2011 | 0 | 0 | 0 | 0 |
| 2012 | 0 | 0 | 0 | 0 |
| 2013 | 0 | 0 | 0 | 0 |
| 2014 | 0 | 0 | 0 | 0 |
| 2015 | 0 | 0 | 0 | 0 |
| 2016 | 0 | 0 | 0 | 0 |
| 2017 | 0 | 0 | 756,000 | -756,000 |
| TOTAL | 7,560,000 | 0 | 756,000 | 6,804,000 |

Appendix I: Cash Flows for Life-Cycle Cost Analysis (Continued)

OPERATING-RELATED COSTS DURING OCCUPANCY

| YEAR | - OPERATING AND MAINTENANCE COSTS - AN RECURRING | NON-AN REC | ENERGY - | TOTAL OPER. COST |
|---|---|---|---|---|
| 1993 | 1,720,000 | 0 | 0 | 1,720,000 |
| 1994 | 1,720,000 | 0 | 0 | 1,720,000 |
| 1995 | 1,720,000 | 0 | 0 | 1,720,000 |
| 1996 | 1,720,000 | 0 | 0 | 1,720,000 |
| 1997 | 1,720,000 | 0 | 0 | 1,720,000 |
| 1998 | 1,720,000 | 0 | 0 | 1,720,000 |
| 1999 | 1,720,000 | 0 | 0 | 1,720,000 |
| 2000 | 1,720,000 | 0 | 0 | 1,720,000 |
| 2001 | 1,720,000 | 0 | 0 | 1,720,000 |
| 2002 | 1,720,000 | 0 | 0 | 1,720,000 |
| 2003 | 1,720,000 | 0 | 0 | 1,720,000 |
| 2004 | 1,720,000 | 0 | 0 | 1,720,000 |
| 2005 | 1,720,000 | 0 | 0 | 1,720,000 |
| 2006 | 1,720,000 | 0 | 0 | 1,720,000 |
| 2007 | 1,720,000 | 0 | 0 | 1,720,000 |
| 2008 | 1,720,000 | 0 | 0 | 1,720,000 |
| 2009 | 1,720,000 | 0 | 0 | 1,720,000 |
| 2010 | 1,720,000 | 0 | 0 | 1,720,000 |
| 2011 | 1,720,000 | 0 | 0 | 1,720,000 |
| 2012 | 1,720,000 | 0 | 0 | 1,720,000 |
| 2013 | 1,720,000 | 0 | 0 | 1,720,000 |
| 2014 | 1,720,000 | 0 | 0 | 1,720,000 |
| 2015 | 1,720,000 | 0 | 0 | 1,720,000 |
| 2016 | 1,720,000 | 0 | 0 | 1,720,000 |
| 2017 | 1,720,000 | 0 | 0 | 1,720,000 |
| TOTAL | 43,000,000 | 0 | 0 | 43,000,000 |

Appendix I: Cash Flows for Life-Cycle Cost Analysis (Continued)

SUM OF ALL CASH FLOWS

| YEAR | CAPITAL INVESTMENT | OPERATING COSTS | TOTAL COST |
|---|---|---|---|
| 1992 | 7,560,000 | 0 | 7,560,000 |
| 1993 | 0 | 1,720,000 | 1,720,000 |
| 1994 | 0 | 1,720,000 | 1,720,000 |
| 1995 | 0 | 1,720,000 | 1,720,000 |
| 1996 | 0 | 1,720,000 | 1,720,000 |
| 1997 | 0 | 1,720,000 | 1,720,000 |
| 1998 | 0 | 1,720,000 | 1,720,000 |
| 1999 | 0 | 1,720,000 | 1,720,000 |
| 2000 | 0 | 1,720,000 | 1,720,000 |
| 2001 | 0 | 1,720,000 | 1,720,000 |
| 2002 | 0 | 1,720,000 | 1,720,000 |
| 2003 | 0 | 1,720,000 | 1,720,000 |
| 2004 | 0 | 1,720,000 | 1,720,000 |
| 2005 | 0 | 1,720,000 | 1,720,000 |
| 2006 | 0 | 1,720,000 | 1,720,000 |
| 2007 | 0 | 1,720,000 | 1,720,000 |
| 2008 | 0 | 1,720,000 | 1,720,000 |
| 2009 | 0 | 1,720,000 | 1,720,000 |
| 2010 | 0 | 1,720,000 | 1,720,000 |
| 2011 | 0 | 1,720,000 | 1,720,000 |
| 2012 | 0 | 1,720,000 | 1,720,000 |
| 2013 | 0 | 1,720,000 | 1,720,000 |
| 2014 | 0 | 1,720,000 | 1,720,000 |
| 2015 | 0 | 1,720,000 | 1,720,000 |
| 2016 | 0 | 1,720,000 | 1,720,000 |
| 2017 | -756,000 | 1,720,000 | 964,000 |
| TOTAL | 6,804,000 | 43,000,000 | 49,804,000 |

(41)

*********************************************************************
* N I S T   B L C C   A N A L Y S I S *
*********************************************************************

## PART I - INITIAL ASSUMPTIONS AND COST DATA

Project name: Do Nothing
Run date: 07-11-1992/09:21:43
Comment: Let existing heat plant operate as is
Input data file: DONOTHNG.DAT, last modified: 07-11-1992/09:04:22
LCC output file: DONOTHNG.LCC, created: 07-11-1992/09:04:25
Study period: 26 years (1992 through 2017)
Discount rate: 7.0% Real (exclusive of general inflation)
Run type: Generic LCC Analysis--No Tax Analysis
BLCC uses end-of-year discounting convention

### INITIAL CAPITAL ASSET COSTS (NOT DISCOUNTED)

| | TOTAL COST |
|---|---|
| TOTAL INITIAL CAPITAL ASSET COSTS | $0 |

### ENERGY-RELATED COSTS

| ENERGY TYPE | UNITS/ YEAR | PRICE ($/UNIT) | DEMAND COST | TOTAL P.V. COST |
|---|---|---|---|---|
| Coal | 12,635 | $58.760 | $0 | $10,066,580 |

*********************************************************************

## PART II - LIFE-CYCLE COST ANALYSIS
DISCOUNT RATE = 7.0% Real (exclusive of general inflation)

PROJECT NAME: Do Nothing    RUN DATE: 07-11-1992/09:21:43

| | PRESENT VALUE (1992 DOLLARS) | ANNUAL VALUE (1992 DOLLARS) |
|---|---|---|
| A. CASH REQUIREMENTS AS OF OCCUPANCY | $0 | $0 |
| C. O&M AND RELATED COSTS: | | |
| ANNUALLY RECURRING COSTS (NO ENERGY) | $11,175,360 | $945,000 |
| ENERGY COSTS | $10,066,580 | $851,240 |
| SUBTOTAL | $21,241,940 | $1,796,241 |
| F. RESIDUAL VALUE OF CAPITAL ASSETS | ( $0) | ( $0) |
| G. TOTAL LIFE-CYCLE PROJECT COST | $21,241,940 | $1,796,241 |

```
**************************************************************************
*                N I S T   B L C C   A N A L Y S I S                     *
**************************************************************************
```

## PART I - INITIAL ASSUMPTIONS AND COST DATA

Project name: Rpl w/Gas
Run date: 07-11-1992/09:21:56
Comment: Replace existing boilers with nat gas fired units
Input data file: REPLACE.DAT, last modified:
07-11-1992/09:00:34
LCC output file: REPLACE.LCC, created: 07-11-1992/09:00:36
Study period: 26 years (1992 through 2017)
Plan/constr. period: 1 years (1992 through 1992)
Occupancy period: 25 years (1993 through 2017)
Discount rate: 7.0% Real (exclusive of general inflation)
Run type: Generic LCC Analysis--No Tax Analysis
BLCC uses end-of-year discounting convention

### INITIAL CAPITAL ASSET COSTS (NOT DISCOUNTED)
### (ADJUSTED FOR PRICE CHANGES DURING PLAN/CONST. PERIOD, IF ANY)

| | YEAR | COST PHASING | YEARLY COST | TOTAL COST |
|---|---|---|---|---|
| | 1992 | 100.0% | $1,200,000 | |
| AT OCCUPANCY: | 1993 | 0.0% | $0 | |
| TOTAL INITIAL CAPITAL ASSET COSTS | | | | $1,200,000 |

### ENERGY-RELATED COSTS

| ENERGY TYPE | UNITS/ YEAR | PRICE ($/UNIT) | DEMAND COST | TOTAL P.V. COST |
|---|---|---|---|---|
| Natural Gas | 3,285,000 | $0.400 | $0 | $18,272,010 |

```
**************************************************************************
```

## PART II - LIFE-CYCLE COST ANALYSIS
### DISCOUNT RATE = 7.0% Real (exclusive of general inflation)

PROJECT NAME: Rpl w/Gas RUN DATE: 07-11-1992/09:21:56

| | PRESENT VALUE (1992 DOLLARS) | ANNUAL VALUE (1992 DOLLARS) |
|---|---|---|
| A. CASH REQUIREMENTS AS OF OCCUPANCY | | |
| DURING CONSTRUCTION | $1,200,000 | $101,473 |
| AT OCCUPANCY | $0 | $0 |
| SUBTOTAL | $1,200,000 | $101,473 |
| C. O&M AND RELATED COSTS: | | |
| ANNUALLY RECURRING COSTS (NO ENERGY) | $10,292,190 | $870,318 |
| ENERGY COSTS | $18,272,010 | $1,545,100 |
| SUBTOTAL | $28,564,200 | $2,415,418 |
| F. RESIDUAL VALUE OF CAPITAL ASSETS | ( $20,663) | ( $1,747) |
| G. TOTAL LIFE-CYCLE PROJECT COST | $29,743,540 | $2,515,144 |

## NIST BLCC ANALYSIS

### PART I - INITIAL ASSUMPTIONS AND COST DATA

Project name: SDA/FF
Run date: 07-11-1992/09:22:09
Comment: Install 100 TPD mod HRI with SDA/FF APC equipment
Input data file: SDAFF.DAT, last modified: 07-11-1992/09:01:30
LCC output file: SDAFF.LCC, created: 07-11-1992/09:01:31
Study period: 26 years (1992 through 2017)
Plan/constr. period: 1 years (1992 through 1992)
Occupancy period: 25 years (1993 through 2017)
Discount rate: 7.0% Real (exclusive of general inflation)
Run type: Generic LCC Analysis--No Tax Analysis
BLCC uses end-of-year discounting convention

INITIAL CAPITAL ASSET COSTS (NOT DISCOUNTED)
(ADJUSTED FOR PRICE CHANGES DURING PLAN/CONST. PERIOD, IF ANY)

| | YEAR | COST PHASING | YEARLY COST | TOTAL COST |
|---|---|---|---|---|
| | 1992 | 100.0% | $8,179,000 | |
| AT OCCUPANCY: | 1993 | 0.0% | $0 | |
| TOTAL INITIAL CAPITAL ASSET COSTS | | | | $8,179,000 |

### PART II - LIFE-CYCLE COST ANALYSIS

DISCOUNT RATE = 7.0% Real (exclusive of general inflation)

PROJECT NAME: SDA/FF RUN DATE: 07-11-1992/09:22:09

| | PRESENT VALUE (1992 DOLLARS) | ANNUAL VALUE (1992 DOLLARS) |
|---|---|---|
| A. CASH REQUIREMENTS AS OF OCCUPANCY | | |
| DURING CONSTRUCTION | $8,179,000 | $691,625 |
| AT OCCUPANCY | $0 | $0 |
| SUBTOTAL | $8,179,000 | $691,625 |
| C. O&M AND RELATED COSTS: | | |
| ANNUALLY RECURRING COSTS (NO ENERGY) | $20,257,630 | $1,713,006 |
| SUBTOTAL | $20,257,630 | $1,713,006 |
| F. RESIDUAL VALUE OF CAPITAL ASSETS | ( $140,839) | ( $11,909) |
| G. TOTAL LIFE-CYCLE PROJECT COST | $28,295,800 | $2,392,722 |

```
*******************************************************************
*              N I S T    B L C C    A N A L Y S I S              *
*******************************************************************

              PART I - INITIAL ASSUMPTIONS AND COST DATA
-------------------------------------------------------------------
          Project name: SDA/ESP
          Run date: 07-11-1992/09:22:03
          Comment: Install 100 TPD mod HRI with SDA/ESP APC equipment
          Input data file: SDAESP.DAT, last modified:
          07-11-1992/09:01:01
          LCC output file: SDAESP.LCC, created: 07-11-1992/09:01:03
          Study period:         26 years (1992 through 2017)
          Plan/constr. period:  1 years (1992 through 1992)
          Occupancy period:     25 years (1993 through 2017)
          Discount rate:   7.0%  Real (exclusive of general inflation)
          Run type: Generic LCC Analysis--No Tax Analysis
          BLCC uses end-of-year discounting convention

                INITIAL CAPITAL ASSET COSTS (NOT DISCOUNTED)
       (ADJUSTED FOR PRICE CHANGES DURING PLAN/CONST. PERIOD, IF ANY)
-------------------------------------------------------------------

                  YEAR    COST PHASING    YEARLY COST     TOTAL COST
                  ----    ------------   -------------   ------------
                  1992       100.0%       $7,560,000
 AT OCCUPANCY:    1993         0.0%               $0
 TOTAL INITIAL CAPITAL ASSET COSTS                        $7,560,000

*******************************************************************

                 PART II  -  LIFE-CYCLE COST ANALYSIS
          DISCOUNT RATE =  7.0% Real (exclusive of general inflation)
-------------------------------------------------------------------
PROJECT NAME: SDA/ESP                    RUN DATE: 07-11-1992/09:22:03

                                          PRESENT VALUE     ANNUAL VALUE
                                         (1992 DOLLARS)   (1992 DOLLARS)
                                         --------------   --------------
A. CASH REQUIREMENTS AS OF OCCUPANCY
   DURING CONSTRUCTION                      $7,560,000         $639,281
   AT OCCUPANCY                                     $0               $0
                                         --------------   --------------
    SUBTOTAL                                $7,560,000         $639,281

C. O&M AND RELATED COSTS:
   ANNUALLY RECURRING COSTS (NO ENERGY)    $18,732,870       $1,584,070
                                         --------------   --------------
    SUBTOTAL                               $18,732,870       $1,584,070

F. RESIDUAL VALUE OF CAPITAL ASSETS      (    $130,180)    (    $11,008)

G. TOTAL LIFE-CYCLE PROJECT COST           $26,162,690       $2,212,344
```

## Appendix K: Regression Equations for Modular HRI Capital Costs and Annual O&M Costs

$$CC_{FF} = 2.4991 + 0.0009(TPD) + 0.0002(STM)$$

$$CC_{ESP} = 2.4991 - 0.005021(TPD) + 0.0002(STM)$$

$$AC_{FF} = 0.1479 - 0.0126(TPD) + 0.0000739(STM) + 0.1110(PN)$$

$$AC_{ESP} = 0.1479 - 0.013921(TPD) + 0.0000739(STM) + 0.1110(PN)$$

where

| | | |
|---|---|---|
| $CC_{FF}$ | = | capital cost for HRI with a SDA/FF, in millions of 1991 dollars (multiply this cost by the appropriate ACF in Appendix E to adjust to a specific location) |
| $CC_{ESP}$ | = | capital cost for HRI with a SDA/ESP, in millions of 1991 dollars (multiply this cost by the appropriate ACF in Appendix E to adjust to a specific location) |
| $AC_{FF}$ | = | annual cost for HRI with a SDA/FF, in millions of 1991 dollars (multiply this cost by the appropriate ACF in Appendix E to adjust to a specific location) |
| $AC_{ESP}$ | = | annual cost for HRI with a SDA/ESP, in millions of 1991 dollars (multiply this cost by the appropriate ACF in Appendix E to adjust to a specific location) |
| TPD | = | facility size in tons per day |
| STM | = | steam output in pounds per hour |
| PN | = | number of full-time employees |

## Appendix L: Sociopolitical Survey

| | | | |
|---|---|---|---|
| **HEALTH RISK QUESTIONS** | | | |
| 1. What level of impact on their health do you feel the public will perceive from the operation of a modular HRI? | Low Impact (1) | Medium Impact (2) | High Impact (3) |
| 2. How will the operation of a modular HRI effect human health compared to current heat plant operations? | Reduced Risk (1) | Unchanged Risk (2) | Increased Risk (3) |
| **SITING/OPERATION QUESTIONS** | | | |
| 3. What effect will the modular HRI have on property values in the local community? | No Effect (1) | Moderate Effect (2) | Major Effect (3) |
| 4. What will be the visual impact of the HRI facility on the surrounding community? | No Impact (1) | Moderate Impact (2) | Major Impact (3) |
| 5. What is the relationship between the Air Force and the local community? | Good Relations (1) | Fair Relations (2) | Poor Relations (3) |
| 6. What degree of influence do environmental groups have in the local area? | Minimal Influence (1) | Moderate Influence (2) | Extreme Influence (3) |
| **MULTIMEDIA POLLUTION QUESTIONS** | | | |
| 7. What will be the aesthetic impact of HRI emissions on air quality compared to current heat plant operations? | Positive Impact (1) | No Impact (2) | Negative Impact (3) |
| 8. What will be the aesthetic impact of HRI emissions on water quality compared to current heat plant operations? | Positive Impact (1) | No Impact (2) | Negative Impact (3) |
| **WASTE REDUCTION QUESTIONS** | | | |
| 9. How does the base waste reduction/recycling program compare with local community programs? | Better (1) | Same (2) | Worse (3) |
| **TOTAL** | | | |

## Appendix M: State and Regional EPA Points of Contact

(16:1-8,B-3 to B-5)

| State | State POC | EPA Region | Region POC |
|---|---|---|---|
| Alabama | 205-271-7700 | 4 | 404-347-3222 |
| Alaska | 907-465-2600 | 10 | 206-442-1270 |
| Arizona | 602-257-2300 | 9 | 415-974-7054 |
| Arkansas | 501-562-7444 | 6 | 214-655-7244 |
| California | 916-322-4203 | 9 | 415-974-7054 |
| Colorado | 303-866-3311 | 8 | 303-293-1730 |
| Connecticut | 203-566-2110 | 1 | 617-565-3273 |
| Delaware | 302-736-5071 | 2 | 201-321-6765 |
| Florida | 904-488-4805 | 4 | 404-347-3222 |
| Georgia | 404-656-3500 | 4 | 404-347-3222 |
| Hawaii | 808-548-6915 | 9 | 415-974-7054 |
| Idaho | 208-334-5840 | 10 | 206-442-1270 |
| Illinois | 217-782-3397 | 5 | 312-886-6418 |
| Indiana | 317-232-3210 | 5 | 312-886-6418 |
| Iowa | 515-281-6284 | 7 | 913-236-2806 |
| Kansas | 913-296-1535 | 7 | 913-236-2806 |
| Kentucky | 502-564-2150 | 4 | 404-347-3222 |
| Louisiana | 504-342-9103 | 6 | 214-655-7244 |
| Maine | 207-289-2811 | 1 | 617-565-3273 |
| Maryland | 301-631-3086 | 3 | 215-597-1260 |
| Massachusetts | 617-727-9800 | 1 | 617-565-3273 |
| Michigan | 517-373-7917 | 5 | 312-886-6418 |
| Minnesota | 612-623-5320 | 5 | 312-886-6418 |
| Mississippi | 601-961-5171 | 4 | 404-347-3222 |
| Missouri | 314-751-8730 | 7 | 913-236-2806 |
| Montana | 406-444-3948 | 8 | 303-293-1730 |
| Nebraska | 402-471-2186 | 7 | 913-236-2806 |

Appendix M: State and Regional EPA Points of Contact (Continued)

| State | State POC | EPA Region | Region POC |
|---|---|---|---|
| Nevada | 702-885-4670 | 9 | 415-974-7054 |
| New Hampshire | 603-271-3503 | 1 | 617-565-3273 |
| New Jersey | 609-292-2885 | 2 | 201-321-6765 |
| New Mexico | 505-827-2835 | 6 | 214-655-7244 |
| New York | 518-457-1415 | 2 | 201-321-6765 |
| North Carolina | 919-733-7015 | 4 | 404-347-3222 |
| North Dakota | 701-224-2374 | 8 | 303-293-1730 |
| Ohio | 614-644-2782 | 5 | 312-886-6418 |
| Oklahoma | 405-271-4677 | 6 | 214-655-7244 |
| Oregon | 503-229-5300 | 10 | 206-442-1270 |
| Pennsylvania | 707-787-2814 | 3 | 215-597-1260 |
| Rhode Island | 401-277-3434 | 1 | 617-565-3273 |
| South Carolina | 803-734-5360 | 4 | 404-347-3222 |
| South Dakota | 605-773-3151 | 8 | 303-293-1730 |
| Tennessee | 615-741-3111 | 4 | 404-347-3222 |
| Texas | 512-458-7541 | 6 | 214-655-7244 |
| Utah | 801-538-6769 | 8 | 303-293-1730 |
| Vermont | 802-244-7347 | 1 | 617-565-3273 |
| Virginia | 804-786-4500 | 3 | 215-597-1260 |
| Washington | 206-459-6170 | 10 | 206-442-1270 |
| West Virginia | 304-348-2754 | 3 | 215-597-1260 |
| Wisconsin | 608-266-2121 | 5 | 312-886-6418 |
| Wyoming | 307-777-7938 | 8 | 303-293-1730 |
| Puerto Rico | 809-725-5140 | 2 | 201-321-6765 |
| Virgin Islands | - | 2 | 201-321-6765 |

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## Vita

Captain Arthur H. Anderson, Jr. was born on 17 April 1960 in Sumter, South Carolina. He graduated from Mililani High School in Mililani Town, Hawaii in 1978 and attended the University of Illinois, graduating with a Bachelor of Science in Mechanical Engineering in May 1982. He received a commission in the USAF and served his first tour of duty at Scott AFB, Illinois. He began as a Mechanical Engineer at Headquarters Military Airlift Command where he managed the Command's Energy Conservation Investment Program. In August 1985 he moved to the 375th Civil Engineering Squadron at Scott AFB, where he worked as the Chief of Environmental and Contract Planning until April 1986. His next assignment was with the 435th Civil Engineering Squadron at Rhein-Main AB, Germany. From May 1986 to September 1988 he worked as an Environmental Planner and a Contract Programmer/Community Planner. He was responsible for construction programming activities as well as the development of Rhein-Main's Base Comprehensive Plan. In October 1988 he became the squadron's Chief of Readiness, and in October 1990 he took charge of the Simplified Acquisition of Base Engineering Requirements Office where he worked until entering the School of Engineering, Air Force Institute of Technology, in June 1991.

Permanent Address: 5848 Access Road
Dayton, Ohio 45431

## Vita

Captain Paul R. Munnell was born on 10 August 1959 in Beaver Falls, Pennsylvania. He graduated from Lincoln High School in Ellwood City, Pennsylvania in 1977 and attended the Pennsylvania State University, graduating with a Bachelor of Science in Civil Engineering in November 1981. He received a commission in the USAF and served his first tour of duty at Scott AFB, Illinois, from April 1983 to July 1987. Assigned to the 375th Civil Engineering Squadron at Scott AFB, he served as Civil Engineer (1983-1984), Chief of Logistics (1984-1985), and Environmental Coordinator (1985-1987). His next assignment was with the 435th Civil Engineering Squadron at Rhein-Main AB, Germany. He served as Environmental Coordinator (1987-1988) and Chief of Resources and Requirements (1989-1991) prior to his assignment to the Air Force Institute of Technology's School of Engineering at Wright-Patterson AFB, Ohio, in June 1991.

Permanent Address: 8774 Cheers Circle
Huber Heights, Ohio 45424

# REPORT DOCUMENTATION PAGE

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A MODEL FOR DETERMINING MODULAR HEAT RECOVERY INCINERATOR FEASIBILITY ON AIR FORCE INSTALLATIONS

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**6. AUTHOR(S)**
Arthur H. Anderson, Jr., Captain, USAF
Paul R. Munnell, Captain, USAF

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
Air Force Institute of Technology, WPAFB OH 45433-6583

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**13. ABSTRACT** *(Maximum 200 words)* This study constructed a model to determine the feasibility of building municipal solid waste (MSW) fired modular heat recovery incinerators (HRIs) on Air Force installations. The model consisted of three gates.

Gate one identified current federal regulatory air emission requirements for various HRI pollutants. It also specified two air pollution control configurations with emission reduction efficiencies capable of achieving these requirements.

Gate two presented a life-cycle cost (LCC) economic analysis methodology. Operational and cost data for existing modular HRIs located in the United States facilitated the development of regression equations that estimate capital and annual operating costs for a modular HRI. Actual cost and operational information from a central heating plant at Wright-Patterson AFB, along with cost data from the regression equations, provided the basis for an example LCC analysis involving modular HRIs. Results of this hypothetical evaluation showed that the LCC for the modular HRI alternatives were both less than the LCC of replacing the existing boiler.

Gate three presented a Likert-scale survey to evaluate the sociopolitical acceptability of the proposed HRI. The survey results indicate the level of effort to process the HRI proposal in accordance with the National Environmental Policy Act.

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